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MODELLING POST-GROWTH AND TRADE

AN OPEN 2-REGION ECOLOGICAL STOCK-FLOW CONSISTENT MODEL

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Summary

This working paper presents a full description of a 2-region post-Keynesian stock-flow consistent (SFC) model. The Post-growth And Development Macroeconomic (PADME) model is a conceptual representation of two linked economies that are each made up of seven sectors. The two regions are linked together through international trade and financial flows. The theoretical framework underpinning the model is that of ecological economics. Specifically, the economies of both regions are dependent on the consumption of natural resources.

In addition to the open nature of the PADME economies, the model contains several original features. The most relevant are cost-induced endogenous technological change, an investment function partially dependent on profits, a novel approach to determining household consumption, and a clear separation between technological development and input substitution. Thanks to these features, PADME is able to simulate the impacts on both economies of a cap-and-trade scheme on domestic resource consumption and resources embedded in imports in one region. This is an important novelty as it expands the role that prices and supply-side polices play in SFC models.

After introducing the model, we conclude the working paper by describing other international macroeconomic policies that can be simulated in PADME and that, to the best of our knowledge, have not been simulated in the SFC literature yet. Specifically, we show how to model a financial transfer and a technology transfer from one region to the other.

1 Introduction

Recent calls have been made to develop more post-growth scenarios (Hickel *et al.*, 2021; Slameršak *et al.*, 2024; Victor and Jackson, 2020). In particular, Gräbner-Radkowitsch and Strunk (2023) point to a lack of modelling works that study the international economics consequences of a post-growth transition in a North-South context. We answer this call by developing the Post-growth And Development Macroeconomic (PADME) model, a stock-flow consistent macroeconomic model inspired by the work of Godley and Lavoie (2007) and based on the principles of ecological macroeconomics (Victor and Jackson, 2020) and post-Keynesian economics (Lavoie, 2022).

The intention behind the development of PADME was to simulate a post-growth transition in one region — called 'North' — while the other region — called 'South' — keeps developing (Leoni et al., 2023). Though the model can be used for many other research questions, many of the modelling choices that have been made throughout the development of the model flow from the aim of simulating the global impacts of a postgrowth transition in the North.

This working paper describes in detail all the equations of the PADME model and the formulation in the model of some key, macroeconomic policies. Section 2 provides a general overview of the model. Section 3 explains the household and government sectors, which represent the biggest share of consumption in the model. Section 4 covers the production sectors and explains in detail the functioning of endogenous technological change in PADME. Section 5 describes the financial sectors, that is the banking sector and the central bank. Section 6 concludes the description of the model by outlining the structure of the labour market, the R&D module and other international components. Finally, the last two sections introduce three policies that can be modelled in PADME. Section 7 explains how a cap-and-trade scheme on produced and imported resources can be simulated. Section 8 describes two international cooperative policies, namely a financial transfer and a technology transfer. In conclusion, Section 9 points towards future simulations using the PADME model.

2 Model overview

This section presents a general description of the PADME model, a conceptual 2-region endogenous growth model.

Following standard post-Keynesian theory, aggregate demand is the driver of growth in the economy. In particular, we have used the approach developed in Jackson and Jackson (2021) to make the growth rate of the economy partially dependant on the growth in labour productivity. Growth is also dependent on the growth in government consumption. In the steady state, the growth rate of labour productivity and government spending must be equal. If government consumption growth was smaller than labour productivity growth, the public debt-to-GDP ratio would permanently decrease as the share of government expenditure on GDP would shrink while tax income would steadily grow. If government consumption growth was constantly higher than labour productivity growth, the supply of labour would need to steadily increase as GDP would grow faster than labour productivity.

The PADME model has two partially autonomous regions linked together by international trade and capital flows. The two regions are called ‘North’ and ‘South’ respectively to highlight the fact that the model has been originally developed to investigate macroeconomic dynamics between global North and global South. Throughout the working paper, we adopt the convention that the terms 'global North' and 'global South' refer to the two real-world regions, whereas 'North' and 'South' refer to the abstract regions of the PADME model.

The PADME model has been built in line with the ecological economic framework, thus the economy is embedded in the environment (Daly and Farley, 2011). *Figure 1* gives a schematic representation of the general structure of the model, where the economies of both North and South are ultimately dependent on resources for production. Given the conceptual nature of the model, 'resources' in PADME are a composite entity taken to represent the material needs of the economy, including both abiotic and biotic resources.

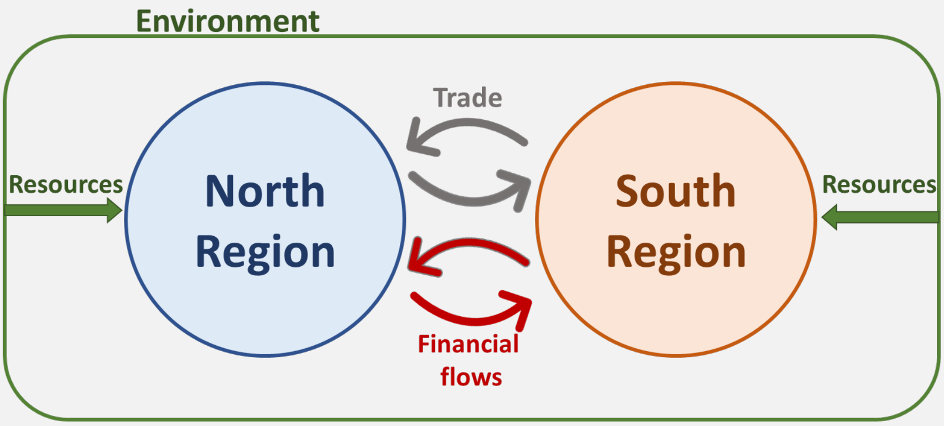

Figure 1: *overview of the structure of the PADME model.*

The economy-environment interaction is kept to a minimum and is only constituted by the extraction of resources by a production sector which we call the resource sector. This choice stems from our desire to focus on macroeconomic dynamics. The way in which the environment is modelled in PADME allows us to maintain resources as the ultimate necessary input for the economy while abstracting from the complexity of developing a sophisticated environmental module.

The remaining part of this section is organised as follows. Subsection 2.1 describes the economic features of the PADME model. Subsection 2.2 illustrates the nomenclature used in the description of the model and explains the logic followed for its calibration. Subsection 2.3 gives a general outline of how to interpret the transaction-flow and balance sheet matrices.

Subsection 2.4 briefly highlights how the PADME model can be transformed in a closed-economy model.

2.1 A non-mathematical description of PADME

Regarding the economic side of the PADME model, the two regions have the same economic structure. The type and number of sectors and the equations governing them are the same. As the two regions are identical, the description covers only one of them. Each region is composed of seven sectors: the household sector, the government sector, the traded sector, the non-traded sector, the resource sector, the banking sector and the central bank. The economic and financial relationships among these sectors are numerous and complicated. To make the presentation of the model more straightforward, the description firstly covers the sectors that can be associated with the real-economy side of the model and then introduces those that play a role in its financial side.

Figure 2 presents a schematic depiction of the real economy, which includes consumption, production, trade and the associated income flows.

The production side is constituted by three sectors : the traded sector, the non-traded sector and the resource sector. The resource sector is very simple. It extracts resources and sell them to the traded sector. It does not employ workers, but it purchases capital from the traded sector. The latter is the only one that exports goods to the other area. It also produces capital for the other firms' sectors. Splitting the production sector between a traded and non-traded sector stems from the literature on post-growth, which highlights the importance of transitioning from manufacturing to service sectors to reduce the environmental footprint of the economy and address some of the imbalances that might arise in a post-growth economy (Jackson, 2017). Conventionally, services are less open to trade than manufacturing (Mano and Castillo, 2015), thus they are proxied by the non-traded sector in the PADME model. Furthermore, services are usually labour-intensive and energy-light (Hardt *et al.*, 2021). Though this is a simplification[1], these stylised facts are replicated in this model.

Concerning their production requirements, both the traded and non-traded sectors need capital, labour and intermediate inputs to produce their output. However, only the traded sector needs resources, while the non-traded sector uses intermediate goods produced by the traded sector of the two regions. In other words, the traded sector is more resource intensive.

1 For instance, sectors such as construction are resource-intensive and labour-intensive but also rarely open to trade. Conversely, there are sectors such as IT services that are resource-light and labour-light and also prone to trade (Hardt *et al.*, 2021; Mano and Castillo, 2015).

Moreover, the labour requirements of the non-traded sector are higher than those of the traded sector, thus making it more labour intensive. A detailed understanding of the differences between these two sectors will be provided in Section 4.

The investment decision of the three sectors is in line with that of other stock-flow consistent models (Godley and Lavoie, 2007; Jackson and Jackson, 2021; Jackson and Victor, 2020). Specifically, firms have a target level of capital that is dependent on desired or expected sales. Their investment decision is aimed at reaching that capital target. The only difference in PADME to this conventional investment function is that desired sales are partially dependent on expected profits. This modification makes investment more volatile than consumption, thus reproducing a famous stylised fact (Abel and Bernanke, 2001). Part of investment is funded through an exogenous share of retained profits while the rest is financed by borrowing from the banking sector. Moreover, an exogenous share of gross profits is spent in R&D activities. Lastly, remaining profits are distributed to the capitalist class.

R&D activities are an important component of the PADME model as they are needed to generate technological innovation. In this context, technology refers to the level of efficiency in the use of productive inputs such as resources, labour and intermediate goods. The modelling of technological change in the PADME model has been based on Naqvi and Stockhammer (2018)and, more generally, on a simplified version of the cost-induced technological change theory (Acemoglu, 2002). Specifically, technological change depends on the levels of research and development (R&D) funding allocated to different input-saving technologies, which in turn partly depend on the relative prices of inputs. R&D is financed both by the firms' sector and the government, while households supply the labour input required to carry out the research activities. Endogenous technological change has been added to the PADME model to properly simulate the macroeconomic impact of a cap on resources. This point is further expanded in Section 7.

The household and government sectors account for most of the consumption of goods and services in the PADME model. The former is divided between two classes: 'workers' receive income in the form of wages, while 'capitalists' are the recipient of capital income. Splitting the household sector into two classes allows us to further examine issues of inequality, which are very prominent in the post-growth literature (Cosme *et al.*, 2017). Households use the majority of their after-tax income to purchase goods produced by the domestic traded sector, the foreign traded sector and the domestic non-traded sector. The allocation of their nominal income to the different goods is determined by relative prices. For instance, if the price of one good increases, the real consumption of that good decreases relative to the others. Section 3 provides a more detailed description of the consumption decision. The share of disposable income that is not consumed is saved. More specifically, workers spend all their income in consumption while capitalists divide their income between consumption and savings.

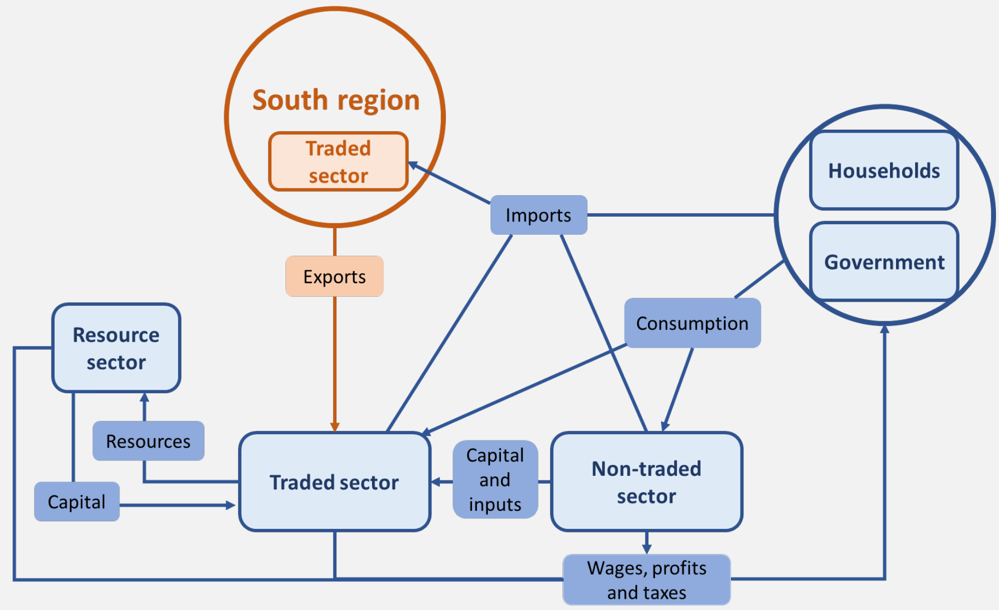

Figure 2: *main monetary flows associated with production and consumption in one region. The direction of the arrows indicates the direction of the income flow. For instance, the traded sector purchases resources from and sells capital to the resource sector.*

The government sector receives income through the collection of taxes on wages, profits and imports. Government consumption is specified in line with that of households, i.e. it is partially dependant on relative prices. The government also devotes an exogenous share of its revenue to financing R&D activities. Lastly, it provides unemployment insurance to unemployed workers. Unemployment insurance is introduced to have a simplified proxy for the welfare state. Adding this proxy allows us to explore how the welfare state is impacted by a post-growth context, another central topic in the post-growth literature (Corlet Walker *et al.*, 2021). When expenditure is higher than the income collected through taxes, the government issues bonds to cover its deficit.

Regarding the financial side of the model, it is first worth mentioning that every sector has a financial side. However, we refer here to those sectors that are primarily involved in lending, selling and purchasing financial assets and determining the interest rates on those assets. These sectors are the banking sector and the central bank.

Figure 3 shows a graphical illustration of this part of the model. As can be seen, the banking sector is at the centre of the financial network. On its liability side, it has its equity and the savings of the household sector held in the form of deposits. On its asset side, it has four different financial assets: domestic government bonds, foreign government bonds, central bank reserves and loans to firms. Government bonds are the only type of asset that is traded internationally. Following the endogenous money theory, commercial banks do not need households' deposits in order to lend to the other sectors (Fontana and Setterfield, 2009). However, they need to keep a certain level of reserves in order to guarantee their ability to meet their liquidity requirements. Banks then decide how to allocate credit to the government and firm sectors. The way this decision is made will be explained in Section 5. The Central Bank provides reserves to the banking sector in exchange for government bonds.

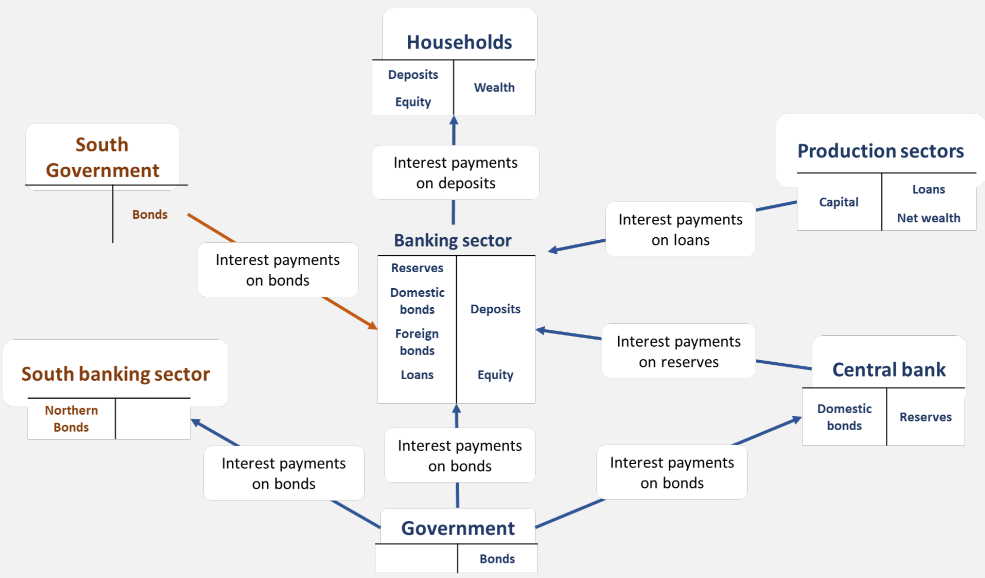

Figure 3: *financial assets and related sectors in the North. The arrows represent the interest flows from debtor to creditor. The balance sheet of the Southern sectors is simplified to include only the variables of interest from the Northern point of view.*

The interest rates on the different assets are endogenous. The only interest rate that is set by the central bank is the rate on reserves, the so-called policy rate. This base rate feeds into the determination of all the other interest rates in the economy. Indeed, the interest rate on government bonds is specified as an exogenous mark-up over the policy rate. Moreover, the banking sector sets an exogenous, fixed mark-up over the policy rate to determine the interest rate that it pays on deposits. Lastly, banks charge a different interest rate on loans to the traded and non-traded sectors based on their level of creditworthiness. Again, this interest rate is computed as an endogenous mark-up over the policy rate.

Having defined the general structure of the PADME model, we now describe its calibration and outline the nomenclature that will be used throughout the working paper to refer to the different variables and sectors of the model.

2.2 Calibration and nomenclature

The calibration of the parameters of the PADME model follows a theoretical approach. As the number of parameters is high, the values of these parameters are not included in the main body of the working paper. However, a full list of the variables and related values can be found in Appendix A, Section A.1 and Section A.2 respectively. In this subsection, we describe the general rationale adopted to calibrate the model.

The process through which the parameter values of the PADME model have been selected follows several steps. First of all, as this is a theoretical model with two identical regions, the value of each parameter is the same in both regions. Secondly, where possible, the values have been selected in accordance with empirical evidence, which was mainly obtained from developed countries' data as this is more easily available. Selecting in accordance with empirical evidence means calibrating the parameters in such a way that their value is approximately close to their real values. It is more a matter of sensible calibration rather than empirical estimation. However, there might have been parameters which values cannot be found in the empirical literature. In that case, values are chosen either by relying on standard values found in the SFC literature or by considering their impact on the stability of the model. An instance of this approach can be found in the way adjustment parameters have been calibrated. Indeed, they all have a value between 0.1 and 0.2. This is in line with the SFC literature (Dafermos *et al.*, 2017; Godley and Lavoie, 2007), but it is also convenient as it generates more stable results. Overall, it is important to bear in mind that the PADME model does not try to reproduce a specific economy and remains theoretical in nature.

Concerning the nomenclature, the PADME model has many variables which are highly interconnected, thus presenting its equations can become confusing. The nomenclature outlined here is an attempt to simplify the exposition by providing few rules of thumb which are used for labelling the variables. A full list of all the variables and related notations can be found in Appendix A, Section A.1.

Firstly, following the standard nomenclature in SFC modelling (Godley and Lavoie, 2007), all nominal variables are in uppercase, while real variables are in lowercase. Secondly, subscripts and superscripts that refers to sectors or to the two areas are in capital letters, whereas those that refer to all the other variables are in lowercase. *Table 1* shows a summary of the main labels used for subscripts and superscripts.

When a variable has the subscript of a sector, it means that that variable belongs to that sector. The term 'belonging' might be a little ambiguous, but in general this means that the specific variable (whether it refers to a flow of income, an asset or a technical parameter) is being used in that specific sector. However, there might be cases where other labels are needed to better qualify the variable. Usually, these labels will be put as superscript.

One instance can clarify the point. The intermediate goods consumed by the non-traded sector in the North are purchased both from the domestic and foreign traded sector. Thus, to refer to the former we use the following notation: ic_D^T, i.e., intermediate consumption ic of the non-traded sector D produced by the traded sector T. For the latter, the notation will be ic_D^m, i.e., intermediate consumption ic of the non-traded sector D coming from imports m.

One exception to this rule concerns the notation for internationally traded bonds. For instance, Southern (S) government bonds (B) *demanded* (d) by the banking sector (subscript B) in the North (N) will be defined as B_{BN}^{Sd}, namely, the subscript also includes the region of the sector that is purchasing the asset while the superscript defines the area of origin of the asset and whether the variable refers to its demand or supply. In any case, if a variable has many labels, we will explicitly define what the labels mean in the text in order to clarify the notation.

Lastly, the symbol Δ represent a first difference, while one-period lagged variables will be represented with the subscript -1, such as x_{-1}. Accented letters such as $\bar{X}$ refers to target variables, while variables with a dotted accent, for instance $\dot{X}$, refers to a growth rate.

Subscripts and superscripts

Sectors

Household	H	Banking	B
Traded sector	T	Government	G
Non-traded sector	D	Central Bank	CB
Resource sector	R		

Regions

North	N	South	S

Other variables and labels

Imports	m	Labour	n
Exports	x	Firms	f
Wages	w	Reserves (high-powered money)	hh
Capital income	c	Demand for an asset	d
Intermediate goods	ic	Supply of an asset	s
Resources	r		

Table 1

2.3 The transaction-flow and balance sheet matrices

A typical feature of the SFC literature is to visually represent the accounting relationships among the different sectors of the model using two matrices: a transaction-flow matrix, which shows the direction of the different income flows in the model, and a balance sheet matrix, which represents the distribution of assets and liabilities among the different sectors.

Appendix B.1 shows the transaction-flow matrix for the PADME model. A few notes can help in interpreting the matrix. The positive and negative signs represent the source and use of funds, respectively. For instance, consumption is a use of funds for the household sector and a source of funds for the firm sectors. The matrix is split into two sections. The first part concerns the movements of income and expenditure flows, while the second part (the one starting below 'changes in stock' in the matrix) illustrate the changes in financial positions. The connection between the two parts is straightforward. All the income that is not spent by a sector (first part) must result in a change in that sector's financial position in the form of an increase in its assets (second part). Conversely, a sector that spends more than it earns must borrow, thus its surplus decreases (or its deficit increases) vis-à-vis the rest of the economy. This change in assets is represented with the symbol Δ. Lastly, for the model to be stock-flow consistent, all rows and columns must sum to zero.

Appendix B.2 shows the balance sheet matrix. Again, a few notes are important to shed light on what this matrix represents. The positive sign means that the variable is an asset, while the negative sign represents a liability. Each financial asset held by a sector is a corresponding liability for another sector. Thus, for the financial assets all rows and columns of the matrix should sum to zero. However, real assets like capital do not have a corresponding liability, therefore a model in which the economy produces capital will have a positive net worth equal to the value of the capital stock.

A simple way to interpret the interaction between these two matrices is to look at them in a dynamic state. At the beginning of each period, the balance sheet matrix gives a sense of the distribution of assets and liabilities within the economy. During each period, income and expenditure flow from one sector to another according to the transaction-flow matrix. The resulting net lending/borrowing positions of the different sectors generated by these flows reflect the new distribution of assets and liabilities at the end of the period. Hence, a new balance sheet matrix will be obtained which will serve as the starting point for a new period.

2.4 Closed-economy PADME model

This last subsection briefly illustrates how it is possible to obtain a closed-economy version of PADME. Basically, given that the economic structure of the two regions is identical, removing one region and all the equations related to the international dimension of the economy is sufficient to obtain a closed-economy PADME model.

In practical terms, this means that the household and government sectors do not consume imports. The traded sector is renamed 'manufacturing' sector and does not export its good nor imports intermediate goods. Similarly, the non-traded sector is renamed 'service' sector and only consumes goods from the manufacturing sector. Import productivity is thus removed from the model. Banks do not purchase international bonds, hence they manage three (instead of four) assets. Lastly, the entire part of the model devoted to trade and exchange rates (Sectio 6, Subsection 6.3) can be overlooked. If these changes are kept in mind, the reader can rely on the description of the 2-region PADME model to understand the core dynamics of the closed-economy PADME model.

3 Consumption sectors

This section focuses on the sectors that constitute the largest part of the consumption side, namely the household and government sectors. As the two regions are identical, there is no need to describe the equations of both. From now on, we present only the equations of the North. When variables belonging to the South appear, they will be defined by the superscript S.

3.1 Household sector

In the PADME model, households are divided into two groups: workers and capitalists. The first group provides labour to the productive sectors and to R&D activities in exchange for wages. Moreover, unemployed workers receive unemployment benefits from the government. In line with many post-Keynesian models and the empirical evidence (Lavoie, 2022), workers have higher propensity to consume than capitalists. Here, we follow the traditional Kaleckian assumption (Hein, 2018; Kalecki, 1965; Rosenbaum, 2015) that wage earners spend all their income and make no savings. Conversely, the capitalist group receives profits from the banking and firm sectors and interest payments on deposits. Capitalists divide their income between consumption and savings, though they can invest their savings only in deposits which pay a minimum interest rate. Adding a more sophisticated portfolio approach as in traditional SFC models is possible but does not significantly improve the results of the model.

We now present the equations of this sector. Firstly, we introduce how households' income is determined, then we describe the consumption function and we discuss how savings are obtained. The supply of labour will be outlined in Section 6. As indicated above, households' nominal disposable income is divided between income from wages YD_w and from capital YD_c:

$$YD_w = (NW + \mho) * (1 - t_w) + G_{ws} \tag{1}$$

$$YD_c = (F_H^f + F_H^B + i_{d_{-1}} D_{H_{-1}}) * (1 - t_c) \tag{2}$$

Where NW is the wage bill, $\mho$ is the income received for R&D activities, G_{ws} is the unemployment insurance paid by the government, F_H^f and F_H^B are distributed profits from the firm[2] and banking sectors and $i_{d_{-1}} D_{H_{-1}}$ is interest payments on deposits. t_w and t_c are the exogenous tax rates on wages and capital income.

Once disposable income is specified, consumption can be determined as:

$$CONS_H = \theta_0 YD_w + \theta_1 YD_c + \theta_2 V_{-1} \tag{3}$$

Where V_{-1} is nominal wealth in the previous period. $\theta_0, \theta_1, \theta_2$ are consumption coefficients and their values are attributed respecting this simple rule: $\theta_0 > \theta_1 > \theta_2$. In other words, the propensity to consume out of income of the capitalists is lower than that of workers, while the propensity to consume out of wealth is the lowest of the three. While θ_0 and θ_2 are exogenous, θ_1 is endogenous and dependant on the change in the interest rate on deposits:

$$\theta_1 = \theta_{1_{-1}} - \nu_0 \Delta i_d \tag{4}$$

ν_0 is the exogenous sensitivity of the propensity to consume of capitalists to the interest rate on deposits. As discussed in Appendix A - Section A.2, in the PADME model this sensitivity is assumed to be low in line with empirical evidence (Agarwal *et al.*, 2021).

The choice of including the interest rate in the determination of θ_1 stems from the desire to make changes in the interest rate more impactful for the economy. In particular, we want to test whether the Taylor-like rule followed by the central bank would be appropriate in a post-growth context (the central bank behaviour is explained in Subsection 5.2). Generally, higher interest rates in SFC models can have a small effect on the economy or even lead to the surprising effect of boosting the economy (see (Godley

2 $F_H^f = F_H^T + F_H^D + F_H^R$. The profits of each specific sector will be presented in Section 4.

and Lavoie, 2007)). The modification in equation 4 is one of the few introduced in the PADME model to make interest rates more relevant for our analysis.

The interest rate on deposits has been chosen as the interest rate of reference for capitalists because they can only invest their savings in deposits. This will be shown later in this subsection. Overall, empirical works show mixed evidence on whether and how interest rates affect households' consumption and saving (Agarwal *et al.*, 2020). This ambiguity might be due to the heterogeneity of households. Agarwal et al. (2021) show that interest-sensitive households react quite strongly to changes in interest rates. In the PADME model, capitalists are the only type of household that is affected by changes in interest rates, thus only their propensity to consume is endogenised.

Once aggregate nominal consumption is determined (equation 3), households need to choose how to allocate nominal consumption to the three different goods that they can purchase, namely non-traded goods $CONS_H^D$, domestically produced traded goods $CONS_H^T$ and imports $CONS_H^m$:

$$CONS_H^D = \alpha_H * CONS_H \tag{5}$$

$$CONS_H^T = (1 - \alpha_H) * \beta_H * CONS_H \tag{6}$$

$$CONS_H^m = CONS_H - CONS_H^T - CONS_H^D \tag{7}$$

Where α_H and β_H are the parameters that determine the share of nominal consumption for the non-traded $CONS_H^D$ and traded goods $CONS_H^T$. Equation 7 means that the consumption of imported goods $CONS_H^m$ is computed as a residual, ensuring that $CONS_H^D + CONS_H^T + CONS_H^m = CONS_H$.

Real consumption $cons_H$ is:

$$cons_H = cons_H^D + cons_H^T + cons_H^m \tag{8}$$

Where real consumption for each good is determined as:

$$cons_H^D = \frac{CONS_H^D}{p_D} \tag{9}$$

$$cons_H^T = \frac{CONS_H^T}{p_T} \tag{10}$$

$$cons_H^m = \frac{CONS_H^m}{p_m} \tag{11}$$

And p_D, p_T, p_m are the price of non-traded, traded and imported goods respectively. In other words, households choose a fixed proportion of nominal income to allocate to the different goods, then real quantities of each good are determined based on their actual price. This formulation of the consumption function might seem odd as real consumption in SFC models is generally determined using equation 3. Namely, households decide their real consumption and then nominal consumption is determined by multiplying real consumption times prices. The rationale for adopting a consumption function that starts from nominal values stems from the desire of simulating the introduction of a cap on resources. This formulation of consumption is necessary for allowing the modelling of the cap. A more detailed description of why this is the case will be given in Section 7.

This different way of modelling consumption yields results that are in line with those of the more conventional method. However, in the former formulation the price elasticity of each good tends to be higher than in the latter one. Moreover, growing divergences between the prices of two goods might lead to an unrealistically low level of real consumption of a given good.

In order to avoid this undesirable outcome, the coefficients α_H and β_H are subject to simple real target consumption constraints $\bar{\alpha}_H$ and $\bar{\beta}_H$. This means that when the real consumption of the non-traded goods becomes higher than the threshold $\bar{\alpha}_H$, the parameter α_H becomes smaller. Similarly, when the real consumption of the imported good becomes smaller than a certain threshold $\bar{\beta}_H$, the parameter β_H starts to grow. This is represented in the model using a conditional operator for both parameter equations:

$$\alpha_H = \begin{cases} \alpha_{H_{-1}} & if \quad \dfrac{cons_H^D}{cons_H} \leq \bar{\alpha}_H \\ \alpha_{H_{-1}} + \alpha_0 \left(\bar{\alpha}_H - \dfrac{cons_H^D}{cons_H} \right) & if \quad \dfrac{cons_H^D}{cons_H} > \bar{\alpha}_H \end{cases} \tag{12}$$

$$\beta_H = \begin{cases} \beta_{H_{-1}} & if \quad \dfrac{cons_H^m}{cons_H} \geq \bar{\beta}_H \\ \beta_{H_{-1}} + \beta_0 \left(\dfrac{cons_H^m}{cons_H} - \bar{\beta}_H \right) & if \quad \dfrac{cons_H^m}{cons_H} < \bar{\beta}_H \end{cases} \tag{13}$$

Where α_0 and β_0 are exogenous parameters.

Once consumption has been determined, capitalists save the remaining part of their income. This is shown in the equation for nominal wealth V, which is:

$$V = V_{-1} + YD_w + YD_c - CONS_H + \Delta OF_B \tag{14}$$

Where ΔOF_B is the change in banks' own funds, which will be explained in Subsection 5.1. Most of household wealth is invested in deposits. This wealth is called investable wealth V_{inv} and is derived as:

$$V_{inv} = V - OF_B \tag{15}$$

In other words, the funds of the banking sector OF_B, i.e., banks' capital, still account as wealth of the capitalists, but cannot be considered as investible wealth as they are used as capital cushion by the banking sector.

As said above, investable wealth can only be invested in deposits D, thus:

$$D_H = V_{inv} \tag{16}$$

Deposits pay an interest rate i_d which will be described in Subsection 5.1.

3.2 Government sector

The government sector has a central role in the PADME model. It collects taxes from wages, imports, capital income and firms' gross profits. Moreover, it has three types of expenditure: consumption of traded, non-traded and imported goods, R&D expenditure and social transfers. When expenditure is higher than the income collected through taxes, the government issues bonds to cover its deficit. What really makes this sector important though is the way in which its expenditure is specified. Public spending grows following an exogenous growth rate, which plays a fundamental role in driving the growth rate of the whole model. Labour productivity growth is also important for the determination of the growth rate of real GDP in the PADME model. Indeed, a positive labour productivity growth rate would be sufficient to generate a growth model if the government sector was not introduced. However, once taxes are added to the model, they drag down growth in the long run (and thus a steady state is impossible to reach) unless government expenditure grows in line with the growth of labour productivity.

The description of the government sector starts from the equation that determines its target real expenditure $\bar{g}$:

$$\bar{g} = \bar{g}_{-1}(1 + \varsigma) \tag{17}$$

Where ς is its growth rate.

The expenditure growth rate ς depends on an exogenous parameter ς_0 and one specific condition, that is, that the level of public debt over nominal GDP $Debt$ does not overcome a certain threshold $\overline{Debt}$. Regardless of whether targeting the debt-to-GDP ratio is a sensible policy choice for a government, this is a common approach to public finances. Once the threshold $\overline{Debt}$ is exceeded, the government progressively reduces ς to contain expenditure and stabilise its debt-to-GDP ratio. In other words, it implements an austerity policy. The equation expressing this approach follows a conditional operator:

$$\varsigma = \begin{cases} \varsigma_0 & if \quad Debt \leq \overline{Debt} \\ \varsigma_0 + \varsigma_1 (\overline{Debt} - Debt_{-1}) & if \quad Debt > \overline{Debt} \end{cases} \tag{18}$$

Where $Debt = \frac{B^s}{Y}$ is the public-debt-to-GDP ratio, $\overline{Debt}$ is the exogenous target threshold, ς_0 is the exogenous steady state growth rate (1% in our calibration) and ς_1 is an exogenous adjustment parameter determining the speed of reduction of government expenditure growth once $\overline{Debt}$ is exceeded.

From equation 18, nominal expenditure G can be written as:

$$G = p_{ds} * \bar{g} \tag{19}$$

Where p_{ds} is the price index for domestic sales and will be explained in Subsection 6.4.

As for the household sector, the allocation of government consumption is based on nominal values. Part of the nominal government budget G is allocated to R&D expenditure $\mho_G$:

$$\mho_G = \Theta_G G \tag{20}$$

Θ_G is exogenously set. Then, nominal government consumption for the three available goods mirrors that of the household sector, with the exogenous parameters α_G and β_G assuming the same values of α_H and β_H:

$$G^D = \alpha_G * (G - \mho_G) \tag{21}$$

$$G^T = (1 - \alpha_G) * \beta_G * (G - \mho_G) \tag{22}$$

$$G^m = (G - \mho_G) - G^D - G^T \tag{23}$$

Where α_G and β_G determine the share of consumption for non-traded and traded goods, G^D and G^T respectively. The consumption of imported goods G^m is determined as a residual to ensure that $G^m + G^D + G^T = G - \mho_G$.

Real government consumption is then obtained again by dividing nominal consumption of each good by their respective prices:

$$g^D = \frac{G^D}{p_D} \tag{24}$$

$$g^T = \frac{G^T}{p_T} \tag{25}$$

$$g^m = \frac{G^m}{p_m} \tag{26}$$

$$g = g^D + g^T + g^m \tag{27}$$

As explained in the previous subsection, relying on nominal values to determine the allocation of consumption runs the risk of obtaining low levels of real consumption of a specific good if lasting divergences in prices occur. Therefore, the parameter α_G and β_G are subject to a real target consumption level. The equations for the parameters of the government sector mirror those of the household sector:

$$\alpha_G = \begin{cases} \alpha_{G_{-1}} & if \quad \frac{g^D}{g} \leq \bar{\alpha}_G \\ \alpha_{G_{-1}} + \alpha_0 \left(\bar{\alpha}_G - \frac{g^D}{g} \right) & if \quad \frac{g^D}{g} > \bar{\alpha}_G \end{cases} \tag{28}$$

$$\beta_H = \begin{cases} \beta_{H_{-1}} & if \quad \frac{g^m}{g} < \bar{\beta}_G \\ \beta_{H_{-1}} + \beta_0 \left(\frac{g^m}{g} - \bar{\beta}_H \right) & if \quad \frac{g^m}{g} < \bar{\beta}_G \end{cases} \tag{29}$$

Where α_0 and β_0 are exogenous parameters.

Lastly, the government pays an exogenous share φ of average nominal wages W_{av} to all unemployed workers U:

$$G_{ws} = \varphi W_{av} U \tag{30}$$

Where the subscript ws stands for 'welfare state'. The wages of the two sectors are identical, thus $W_{av} = W_D = W_T$. Unemployed workers U are determined as total labour force Q minus employed workers N, i.e. $U = Q - N$. Both wage determination, Q and N are described in Subsection 6.1.

Total nominal expenditure of the government before interest payments on public debt is:

$$G_{tot} = G + G_{ws} \tag{31}$$

It is worth highlighting that only G contributes to GDP, whereas G_{ws} is effectively a transfer.

Having described the government's main outflows, we now focus on its inflows, that is, the tax revenue.

The taxes collected on wages T_w are computed as an exogenous tax rate t_w on workers and researchers' wage income, NW and $\mho$ respectively:

$$T_w = t_w(NW + \mho) \qquad (32)$$

Taxes on capital income T_c are determined as an exogenous tax rate t_c on the sum of firms' distributed profits F_H^f, banks' distributed profits F_H^B and interest payments on deposits $i_{d_{-1}} D_{H_{-1}}$:

$$T_c = t_c(F_H^f + F_H^B + i_{d_{-1}} D_{H_{-1}}) \qquad (33)$$

Taxes on firms' profits T_f are computed as an exogenous tax rate t_f on the sum of the gross profits of the traded F_T, non-traded F_D and resource sector F_R:

$$T_f = t_f(F_T + F_D + F_R) \qquad (34)$$

In line with what happens in many countries, profits are taxed twice, both at the firm level t_f and when distributed to households t_c.

The tariff income collected from imports T_m is equal to nominal imports times the tariff rate $(t_m - 1)$. In the steady state $t_m$is equal to 1, thus the tariff rate and tariff income are equal to zero. However, the introduction of a cap on imported resources — described in Section 7 — makes the tariff rate higher than 1.

$$T_m = (t_m - 1)M \qquad (35)$$

Once all these different tax incomes are summed, we obtain the total tax income T:

$$T = T_w + T_c + T_f + T_m \qquad (36)$$

Lastly, the government issues bonds in order to cover its deficit:

$$B^s = \left(G_{tot} + B_{-1}^s + i_{g_{-1}} B_{-1}^s\right) - (T + F_{CB}) \qquad (37)$$

F_{CB} is the profit of the central bank. The interest rate on government bonds i_g is endogenous. Both F_{CB} and i_g are described in Subsection 5.2. The supply of bonds is divided between the domestic central bank B_{CB}^s and domestic and foreign banks (B_B^s and B_{BS}^{Ns} respectively):

$$B_{CB}^s = B_{CB}^d \qquad (38)$$

$$B_B^s = B_B^d \qquad (39)$$

$$B_{BS}^{Ns} = B^s - (B_{CB}^s + B_B^s) \qquad (40)$$

The supply of bonds to the central bank and the domestic banking sector are equal to their demands B^d_{CB} and B^d_B. These are described in Section 5. The supply to the other region's banks B^{Ns}_{BS} is the residual, guaranteeing that $B^{Ns}_{BS} + B^s_{CB} + B^s_B = B^s$. The stock-flow consistency of the PADME model ensures that B^{Ns}_{BS} is equal to its demand B^{Nd}_{BS} — which will be described in Subsection 5.1. These equations conclude the description of the government sector.

4 Production sectors

This section describes the PADME model's production sectors, namely the traded sector, the non-traded sector and the resource sector. Again, only the equations of the North are described as they are identical in the South.

4.1 Traded sector

We start by presenting the equations of the traded industry as it is the most important of the three sectors. Indeed, it produces the only good that can be traded across the two areas and it is also the only sector that produces capital for itself and the other industries. Moreover, only the traded sector uses natural resources to produce its output. The other two inputs used in the production of the traded good are labour and imported goods from the other area's traded sector.

Technological development is represented by the dynamics of input productivities, i.e., how efficiently inputs are employed to produce the traded good. The productivity growth rate of each input depends on the amount of R&D funding devoted to it, while the allocation of R&D funding to the different input-saving technologies is partly exogenous and partly depends on the inflation rate of the specific input price. This formulation is inspired by the work of Naqvi and Stockhammer (2018) and is thoroughly described in this section.

Lastly, profits are partly retained for financing investment and R&D activities and partly distributed. The amount of investment that is not covered by retained profits is financed through borrowing from the banking sector.

We begin the description of the traded sector by outlining how real sales and gross value added are determined. Real sales are the sum of all goods and capital sold in the economy:

$$s_T = cons^T_H + g^T + ic^T_D + inv_T + inv_D + inv_R + x_T \tag{41}$$

ic_D^T is intermediate consumption of the non-traded sector. inv_T, inv_D and inv_R stand for real investment of the traded, non-traded and resource sector respectively. x_T are real exports. In other words, the goods produced by the traded sector are purchased for consumption by households and the government, as an input for production by the non-traded sector, as capital by all the three productive sectors in the North and are also exported to the other area. The export of traded goods is a function of the demand of the foreign traded sector, the foreign household sector and the foreign government sector. Its equation will be described in Subsection 6.3.

Nominal sales are:

$$S_T = p_T(\, cons_H^T + g^T + ic_D^T + inv_T + inv_D + inv_R) + p_x x_T \qquad (42)$$

Where p_T is the price for the domestic economy and is described below in this subsection. In short, it follows a traditional post-Keynesian pricing equation, where an exogenous mark-up is added to unit costs. p_x is the export price and depends on p_T, on the foreign price p_T^S and on the exchange rate. Its equation follows the conventional form introduced in Godley and Lavoie (2007)and is described in Subsection 6.3.

Real gross value added is real sales minus intermediate consumption of the traded sector. Thus:

$$y_T = s_T - ic_T^m - r_T \qquad (43)$$

That is, intermediate consumption of the traded sector is constituted by imported goods from the other area ic_T^m and resources r_T purchased from the domestic resource sector. Nominal gross value added is:

$$Y_T = S_T - IC_T^m - R_T \qquad (44)$$

Where $IC_T^m = p_m ic_T^m$ and $R_T = p_R r_T$, i.e., real inputs times their prices.

In order to produce its output, the traded sector needs capital and the other three productive inputs. We first describe how capital and investment are determined. The formulation here is similar to those of conventional stock-flow consistent models (Godley and Lavoie, 2007; Jackson and Jackson, 2021). Firms target a specific level of capital $\bar{k}_T$ based on an exogenous output-to-capital ratio κ. However, the output that they target to determine the target capital is not lagged output as in Godley and Lavoie (2007), but rather their desired (target) output $\bar{s}_T$ for the next period, which is based on expected sales and expected profits.

This choice is motivated by the desire of making the investment function slightly more realistic. Indeed, although the evidence that investment depends on sales is robust (Chirinko, 1993), the common formulation used in SFC models tends to generate very stable investment, which is rather unrealistic as investment is one of the most volatile components of GDP. Adding expected profits allows to obtain investment that is more volatile than consumption, which is a regular empirical finding.

From a theoretical perspective, expected profits have been traditionally considered a crucial variable for the determination of investment. Empirical evidence seems to support this view (Bond *et al.*, 2004; Cummins *et al.*, 2006; Gennaioli *et al.*, 2016). For the sake of simplicity, expectations here are adaptive, thus they are represented by lagged real sales and lagged real profits respectively. However, adaptive expectation could be questioned as an appropriate proxy for profit expectations. In this regard, two arguments can be advanced. Firstly, recent empirical work shows that CFOs' expectations regarding future profits can be consistently predicted by relying on publicly available information such as past profitability (Gennaioli *et al.*, 2016). Thus, expectations are not perfectly rational and can be well approximated by an adaptive function. Moreover, it has to be noted that there is also sufficient, though admittedly inconclusive, evidence that investment depends on past profits (Carruth *et al.*, 2000; Glyn, 1997). Overall, the specification that is presented below seems fairly robust.

Target sales are:

$$\bar{s}_T = \kappa_0 s_{T_{-1}} + \kappa_1 \frac{F_{T_{-1}}}{p_{ds_{-1}}} \tag{45}$$

Where κ_0 and κ_1 are exogenous parameters that weight the importance of one variable over the other. Their value is chosen so that the κ_0 has more influence on the determination of $\bar{s}_T$ than κ_1 to avoid an excessively unrealistic volatility of the investment function (Appendix A, Section A.2). $\frac{F_{T_{-1}}}{p_{ds_{-1}}}$ is lagged real profits. F_T is presented below, while the price index p_{ds} is described in section 6.4.

Next, the target capital is derived by dividing target sales by the exogenous technical coefficient κ, which represents the output-to-capital ratio:

$$\bar{k}_T = \frac{\bar{s}_T}{\kappa} \tag{46}$$

Real investment is then determined by a standard partial adjustment function:

$$inv_T = \mu_T(\bar{k}_T - k_{T_{-1}}) + \delta k_{T_{-1}} \tag{47}$$

$\delta k_{T_{-1}}$ is depreciated capital (δ is exogenously determined) and $\mu_T < 1$ is the exogenous partial adjustment coefficient. Real investment then adds to the real capital stock as follows:

$$k_T = (1-\delta)k_{T_{-1}} + inv_T \tag{48}$$

Nominal gross investment and nominal capital stock are:

$$INV_T = p_T inv_T \tag{49}$$

$$K_T = (1-\delta)K_{T_{-1}} + INV_T \tag{50}$$

This concludes the description of the equations that determine investment and the accumulation of the capital stock.

Next, we describe how technological change works at the sectoral level. Technological change in the PADME model is represented by the dynamics of input productivities. Investment in R&D determines the growth rates of these productivities. Private companies and the government decide a share of their budget that they spend on R&D. Then, their decision on how much of the R&D funds to allocate to labour-saving, resource-saving and import-saving technologies affects the growth rates of the different input productivities. The allocation process is partly exogenous and partly depends on the rates of inflation of input prices. Once the R&D investment in one period is decided, the new input productivities computed in that period are embedded in new capital vintages through investment and added to the existing capital stock. The weighted average of new and past productivities determines the current productivity levels. Embedding productivities in capital allows to simulate path dependant technological change, which is an important feature of modelling technology (Aghion *et al.*, 2019). Current productivity levels are then used to estimate the input requirements for the traded sector based on its output production.

After this brief introduction, we can describe the actual equations of the PADME model. Initially, firms plan a target level of input that they would like to employ given the real sales of the period. Thus:

$$\bar{N}_T = \frac{s_T}{\lambda_T} \tag{51}$$

$$\bar{\iota c}^m_T = \frac{s_T}{\xi_T} \tag{52}$$

$$\bar{r}_T = \frac{s_T}{\pi_T} \tag{53}$$

Where $\bar{N}_T, \bar{\iota c}^m_T$ and $\bar{r}_T$ are the target levels for labour, imported goods and resources while λ_T, ξ_T and π_T are their respective productivities. Before moving to the actual level of inputs employed, we describe how productivities are specified and determined. All productivities are embedded in the capital stock as in Jackson and Jackson (2021)[3]. Each new capital vintage, i.e., new investment, embeds different levels of productivity compared to previous capital. Thus, productivities in every period are determined as follows:

$$\lambda_T = \frac{\lambda_{T_{-1}}\left(k_{T_{-1}} - \delta k_{T_{-1}}\right) + \lambda_T^{new}(inv_T)}{k_T} \tag{54}$$

$$\xi_T = \frac{\xi_{T_{-1}}\left(k_{T_{-1}} - \delta k_{T_{-1}}\right) + \xi_T^{new}(inv_T)}{k_T} \tag{55}$$

$$\pi_T = \frac{\pi_{T_{-1}}\left(k_{T_{-1}} - \delta k_{T_{-1}}\right) + \pi_T^{new}(inv_T)}{k_T} \tag{56}$$

Where $\lambda_T^{new}, \xi_T^{new}$ and π_T^{new} are the new productivity levels. The term $\lambda_{T_{-1}}\left(k_{T_{-1}} - \delta k_{T_{-1}}\right)$ indicates that the scrapping of depreciated capital replaces previous levels of productivity that were embedded in the old capital stock. In other words, the productivity levels in each period for the different inputs are a weighted average of the past productivity attached to the remaining capital stock and the new productivity embedded in investment $\lambda_T^{new}(inv_T)$. New productivities $\lambda_T^{new}, \xi_T^{new}$ and π_T^{new} are determined as:

$$\lambda_T^{new} = \lambda_{T_{-1}}^{new}\left(1 + \lambda_T^{gt}\right) \tag{57}$$

$$\xi_T^{new} = \xi_{T_{-1}}^{new}\left(1 + \xi_T^{gt}\right) \tag{58}$$

$$\pi_T^{new} = \pi_{T_{-1}}^{new}\left(1 + \pi_T^{gt}\right) \tag{59}$$

Where λ_T^{gt}, $\xi_T^{gt}$and π_T^{gt} are endogenous growth rates (superscript gt) and depend on the share of national R&D funds allocated to that specific input-saving technology $\left(\frac{\mho_T^n}{\mho_T^{tot}}, \frac{\mho_T^{ic}}{\mho_T^{tot}}, \frac{\mho_T^r}{\mho_T^{tot}}\right)$ and the R&D-to-GDP ratio of the overall economy $\frac{y_{R\&D}}{y}$ (Naqvi and Stockhammer, 2018):

$$\lambda_T^{gt} = \lambda_0\left(\frac{\mho_T^n}{\mho_T^{tot}} + \frac{y_{R\&D}}{y}\right) \tag{60}$$

$$\xi_T^{gt} = \xi_0\left(\frac{\mho_T^{ic}}{\mho_T^{tot}} + \frac{y_{R\&D}}{y}\right) \tag{61}$$

$$\pi_T^{gt} = \pi_0\left(\frac{\mho_T^r}{\mho_T^{tot}} + \frac{y_{R\&D}}{y}\right) \tag{62}$$

λ_0, ξ_0 and π_0 are exogenous parameters that convert the sum of the two ratios in equations 60, 61 and 62 into sensible growth rates for the

3 However, in this model the tracking of the different levels of productivity in the different period is more simplified than in their work.

productivities of the three inputs. In particular, they ensure that $\lambda_T^{gt} = 0.01$, $\xi_T^{gt} = 0$ and $\pi_T^{gt} = 0$ in the steady state.

The ratios $\frac{\mho_T^n}{\mho_T^{tot}}$, $\frac{\mho_T^{ic}}{\mho_T^{tot}}$ and $\frac{\mho_T^r}{\mho_T^{tot}}$ represent the share of the national R&D budget devoted to a specific input productivity. The higher the share, the faster the growth rate of that productivity. These variables are described in more detail below. $\frac{y_{R\&D}}{y}$ is the ratio of R&D spending over national GDP and reflects the idea that more R&D spending relative to total output increases the general level of productivity of the economy (a detailed description of the equation can be found in Subsection 6.2).

$\mho_T^{tot}$ is the sum of R&D funding devoted to the traded sector by the sector itself $\mho_T$ and by the government $(\varrho_n^{GT} + \varrho_{ic}^{GT} + \varrho_r^{GT})\mho_G$:

$$\mho_T^{tot} = \mho_T + (\varrho_n^{GT} + \varrho_{ic}^{GT} + \varrho_r^{GT})\mho_G \tag{63}$$

The second term of equation 63 will become clear with the next equation. Following Naqvi and Stockhammer (2018), the allocation of research funds to the different productivities of the traded sector ($\mho_T^n, \mho_T^{ic}, \mho_T^r$) is partly made through a portfolio approach *à la* Tobin:

$$\begin{pmatrix} \mho_T^n \\ \mho_T^{ic} \\ \mho_T^r \end{pmatrix} = \begin{pmatrix} \varrho_n^{GT} \\ \varrho_{ic}^{GT} \\ \varrho_r^{GT} \end{pmatrix} \mho_G + \left[\begin{pmatrix} \varrho_0^T \\ \varrho_1^T \\ \varrho_2^T \end{pmatrix} + \begin{pmatrix} \varrho_{00}^T & \varrho_{01}^T & \varrho_{02}^T \\ \varrho_{10}^T & \varrho_{11}^T & \varrho_{12}^T \\ \varrho_{20}^T & \varrho_{21}^T & \varrho_{22}^T \end{pmatrix} \begin{pmatrix} \dot{W}_T \\ \dot{p}_m \\ \dot{p}_R \end{pmatrix} \right] \mho_T \tag{64}$$

ϱ_n^{GT}, ϱ_{ic}^{GT} and ϱ_r^{GT} determine the shares of government R&D expenditure $\mho_G$ allocated to the different input-saving technologies for the traded sector and are exogenously set based on government's priorities. The sum of their values is $\varrho_n^{GT} + \varrho_{ic}^{GT} + \varrho_r^{GT} = 0.5$ as the other half of public R&D expenditure is used by the government to fund R&D activities of the non-traded sector.

ϱ_0^T, ϱ_1^T and ϱ_2^T partly shape the distribution of firms' R&D funding $\mho_T$ and are standard exogenous parameters of a portfolio approach. Clearly, their value must sum to 1. However, firms' allocation of funding is also partly endogenous as it reacts to the inflationary dynamics of input prices $\dot{W}_T, \dot{p}_m$ and $\dot{p}_R$. This follows from the well-established idea in the induced technological change literature that technological change is driven by the relative price of input costs (Acemoglu, 2002). The values of the parameter in matrix $\begin{matrix} \varrho_{00}^T & \varrho_{01}^T & \varrho_{02}^T \\ \varrho_{10}^T & \varrho_{11}^T & \varrho_{12}^T \\ \varrho_{20}^T & \varrho_{21}^T & \varrho_{22}^T \end{matrix}$ follow the standard rules of portfolio allocation presented in Godley and Lavoie (2007). Thus, each row and each column sums to zero.

To sum up, the allocation of R&D funding determines the level of productivity growth of the different inputs. This allocation is partly exogenous and partly endogenised through the dynamics of the rates of inflation of input prices. Once the new levels of inputs productivity are determined, they are embedded in new capital vintages, i.e., real investment, and added to the existing capital stock. The weighted average of new and past productivities determines the current productivity levels. These are then used to estimate target input requirements given firms' real sales in the period.

Once target inputs are determined, actual inputs are employed depending on the inflation rate of the specific input price:

$$N_T = \frac{\bar{N}_T}{1 + \epsilon_0 \Delta \dot{W}_T - \epsilon_1 \Delta \dot{p}_m - \epsilon_1 \Delta \dot{p}_R} \tag{65}$$

$$ic_T^m = \frac{\overline{ic}_T^m}{1 + \epsilon_0 \Delta \dot{p}_m - \epsilon_1 \Delta \dot{W}_T - \epsilon_1 \Delta \dot{p}_R} \tag{66}$$

$$r_T = \frac{\bar{r}_T}{1 + \epsilon_0 \Delta \dot{p}_R - \epsilon_1 \Delta \dot{W}_T - \epsilon_1 \Delta \dot{p}_m} \tag{67}$$

This formulation means that in the short run firms are able to reduce the use of a specific input if there is a spike in its price by employing more of the other inputs. ϵ_0 and ϵ_1 are exogenous parameters that regulate the sensitivity of substitution between inputs. This substitution effect only works in the short run as the long run increase in efficiency is determined by higher productivities embedded in new capital vintages, in other words by technological innovation.

The rationale for this formulation stems from a modelling necessity. Indeed, explicitly including prices in the determination of inputs allows us to model the cap on resources (Section 7 provides a more thorough introduction to the cap and how it works). At the same time, our approach to input determination highlights the important difference between substitutability and technological change (Sue Wing, 2006). In the short run, changes in relative prices allow for modest degrees of substitution between productive inputs without requiring new technology. However, in the long run, only new technologies stimulated by R&D can bring about a steady increase in production efficiency. This process has been empirically demonstrated for the energy intensity of the US economy by Sue Wing (2008).

Given the level of inputs needed for production, it is possible to derive the price of the traded good. Prices in the PADME model follow the standard post-Keynesian approach (Lavoie, 2022), i.e., they are obtained as a mark-up over unit costs. Thus, the price p_T for this sector is:

$$p_T = (1 + \eta_T)\left(\frac{W_T N_T + IC_T^m + R_T}{s_T}\right) \quad (68)$$

η_T is the exogenous mark-up.

Having defined how production and prices are determined, we turn to the financial side of the sector. Starting from firms' revenue, which is nominal sales S_T, profits before taxes F_T can be derived as follows:

$$F_T = S_T - W_T N_T - IC_T^m - R_T - i_{T_{-1}} L_{T_{-1}} \quad (69)$$

Where $i_{T_{-1}} L_{T_{-1}}$ is the cost of debt, i.e., the sector-specific interest rate times the stock of loans borrowed by the traded sector.

Gross profits are then allocated to different uses. Part of them has to be paid to the government in the form of corporate taxes $T_T = t_f F_T$ (see also equation 34). Next, firms retain a share of profit F_T^u equal to an exogenous share ϑ_T of nominal investment INV_T:

$$F_T^u = \vartheta_T INV_T \quad (70)$$

Another part of profits is devoted to R&D:

$$\mho_T = \Theta_T F_T \quad (71)$$

Where Θ_T is an exogenous share. The residual part of profits is distributed:

$$F_H^T = F_T - \mho_T - T_T - F_T^u \quad (72)$$

Lastly, firms finance the investment not covered by undistributed profits by borrowing from banks:

$$L_T = INV_T + L_{T_{-1}} - F_T^u \quad (73)$$

4.2 Non-traded sector

The non-traded sector behaves very similarly to the traded sector. The main differences are that the non-traded sector purchases capital from the traded sector, it only sells to the domestic economy and its productive inputs are labour and intermediate goods purchased from the traded sectors of the two countries. The idea of adding a non-traded sector reflects the attempt to model a proxy of the service sector. This choice stems from the emphasis given on structural transition in the literature on post-growth. In particular, post-growth scholars (Jackson, 2017) argue that a sustainable economy will necessarily invest more in sectors that are not resource intensive and still provide important services for human welfare. Having this sector in the model allows for simulating this structural transition and reflecting on its macroeconomic implications both at the domestic and international level.

The standard features of the service sector are usually considered its low involvement in international trade, labour-intensive production and low labour productivity growth (Mano and Castillo, 2015). Though these are rough simplifications and reality is much more heterogenous, the PADME model tries to replicate these stylised facts. One aspect that is worth mentioning here is that by making the non-traded sector more labour intensive, its price becomes higher than that of the traded sector. It is also possible to add a lower labour productivity growth rate in the non-traded sector. This makes the inflation rate of the price of its good higher than that of the tradable good. It also leads to a growing share of workers being employed in the non-traded sector. However, this specification does not add much to the analysis. Hence, labour intensity is the only difference in labour use between the traded and non-traded sectors.

The description of the equations of the non-traded sector follows the same order of the previous subsection. Thus, we start by showing how production and required inputs are determined. Next, we outline the determination of prices and how profits are distributed. Real output is:

$$s_D = cons^D + g^D \tag{74}$$

And nominal output is:

$$S_D = p_D y_D \tag{75}$$

Where p_D is the price of non-traded goods. Real and nominal gross value added of the sector are:

$$y_D = s_D - ic_D^T - ic_D^m \tag{76}$$

$$Y_D = S_D - IC_D^T - IC_D^m \tag{77}$$

Where $IC_D^T = p_T ic_D^T$ and $IC_D^m = p_m ic_D^m$.

Real investment follows a partial adjustment mechanism as in the previous sector. There is again a target level of real capital $\bar{k}_D$ depending on target sales $\bar{s}_D$ and an exogenous technical coefficient κ:

$$\bar{k}_D = \frac{\bar{s}_D}{\kappa} \tag{78}$$

Target sales depends on expected output and expected real profits. Again, expectations are adaptive thus:

$$\bar{s}_D = \kappa_0 s_{D_{-1}} + \kappa_1 \frac{F_{D_{-1}}}{p_{ds_{-1}}} \tag{79}$$

Where κ_0 and κ_1 are exogenous parameters that weight the importance of the two variables in determining the desired level of real sales.

Firms try to reach the target level through new investment:

$$inv_D = \mu_D\left(\bar{k}_D - k_{D_{-1}}\right) + \delta k_{D_{-1}} \tag{80}$$

Where $\delta k_{D_{-1}}$ is depreciated capital and $\mu_D < 1$ is again the exogenous partial adjustment parameter. The real capital stock is then:

$$k_D = (1-\delta)k_{D_{-1}} + inv_D \tag{81}$$

Nominal capital stock and nominal gross investment are:

$$INV_D = p_T inv_D \tag{82}$$

$$K_D = (1-\delta)K_{D_{-1}} + INV_D \tag{83}$$

The price of the traded sector p_T is used to obtain the nominal values as capital is purchased from that sector.

Concerning its non-capital inputs, the non-traded sector employs labour N_D, imported goods ic_D^m and domestic traded goods ic_D^T. The overall determination of each input is the same as in the traded sector:

$$\bar{N}_D = \frac{s_D}{\lambda_D} \tag{84}$$

$$\overline{ic}_D^m = \frac{s_D}{\xi_D^S} \tag{85}$$

$$\overline{ic}_D^T = \frac{s_D}{\xi_D^T} \tag{86}$$

Where $\bar{N}_D, \overline{ic}_D^m$ and $\overline{ic}_D^T$ are the target levels of labour, imported goods and domestic traded goods required for production. λ_D, ξ_D^m and ξ_D^T are the respective productivities of these inputs. These productivities are embedded in new capital purchased by the traded sector. Embedded technologies and the determination of productivity dynamics are identical to the traded sector, just with different inputs. Therefore, we present the equations without an in-depth description, which can be found in the previous subsection. The current levels of input productivities are again the weighted averages between new and old levels:

$$\lambda_D = \frac{\lambda_{D_{-1}}\left(k_{D_{-1}} - \delta k_{D_{-1}}\right) + \lambda_D^{new}(inv_D)}{k_D} \tag{87}$$

$$\xi_D^m = \frac{\xi_{D_{-1}}^m\left(k_{D_{-1}} - \delta k_{D_{-1}}\right) + \xi_D^{mnew}(inv_D)}{k_D} \tag{88}$$

$$\xi_D^T = \frac{\xi_{D_{-1}}\left(k_{D_{-1}} - \delta k_{D_{-1}}\right) + \xi_D^{Tnew}(inv_D)}{k_D} \tag{89}$$

New labour productivities grow following endogenous growth rates:

$$\lambda_D^{new} = \lambda_{D_{-1}}^{new}\left(1 + \lambda_D^{gt}\right) \tag{90}$$

$$\xi_D^{mnew} = \xi_{D_{-1}}^{mnew}\left(1 + \xi_D^{mgt}\right) \tag{91}$$

$$\xi_D^{Tnew} = \xi_{D_{-1}}^{Tnew}\left(1 + \xi_D^{Tgt}\right) \tag{92}$$

Where λ_D^{gt}, ξ_D^{mgt} and ξ_D^{Tgt} are the endogenous growth rates and, as in the traded sector, their values depend on the allocation of R&D funding:

$$\lambda_D^{gt} = \lambda_0\left(\frac{\mho_D^n}{\mho_D^{tot}} + \frac{y_{R\&D}}{y}\right) \tag{93}$$

$$\xi_D^{mgt} = \xi_0^m\left(\frac{\mho_D^m}{\mho_D^{tot}} + \frac{y_{R\&D}}{y}\right) \tag{94}$$

$$\xi_D^{Tgt} = \xi_0^T\left(\frac{\mho_D^T}{\mho_D^{tot}} + \frac{y_{R\&D}}{y}\right) \tag{95}$$

λ_0, ξ_0^m and ξ_0^T are exogenous parameters. $\mho_{tot}^D$ is determined as the sum of R&D funding devoted to the non-traded sector by the sector itself and by the government:

$$\mho_D^{tot} = \mho_D + (\varrho_n^{GD} + \varrho_m^{GD} + \varrho_{ic}^{GD})\mho_G \tag{96}$$

The allocation of research funds to the different productivities partially follows a portfolio approach *à la* Tobin:

$$\begin{pmatrix} \mho_D^n \\ \mho_D^m \\ \mho_D^T \end{pmatrix} = \begin{pmatrix} \varrho_n^{GD} \\ \varrho_m^{GD} \\ \varrho_{ic}^{GD} \end{pmatrix}\mho_G + \left[\begin{pmatrix} \varrho_0^D \\ \varrho_1^D \\ \varrho_2^D \end{pmatrix} + \begin{pmatrix} \varrho_{00}^D & \varrho_{01}^D & \varrho_{02}^D \\ \varrho_{10}^D & \varrho_{11}^D & \varrho_{12}^D \\ \varrho_{20}^D & \varrho_{21}^D & \varrho_{22}^D \end{pmatrix}\begin{pmatrix} \dot{W}_D \\ \dot{p}_m \\ \dot{p}_T \end{pmatrix}\right]\mho_D \tag{97}$$

Where $\varrho_n^{GD} + \varrho_m^{GD} + \varrho_{ic}^{GD} = 0.5$ such that $\varrho_n^{GD} + \varrho_m^{GD} + \varrho_{ic}^{GD} + \varrho_n^{GT} + \varrho_{ic}^{GT} + \varrho_r^{GT} = 1$. In other words, this ensures that all of government R&D funding is allocated to the two sectors. Moreover, $\varrho_0^D + \varrho_1^D + \varrho_2^D = 1$ and each row and column of the matrix $\begin{matrix} \varrho_{00}^D & \varrho_{01}^D & \varrho_{02}^D \\ \varrho_{10}^D & \varrho_{11}^D & \varrho_{12}^D \\ \varrho_{20}^D & \varrho_{21}^D & \varrho_{22}^D \end{matrix}$ sums to zero.

Lastly, the actual inputs employed are:

$$N_D = \frac{\overline{N}_D}{1 + \epsilon_0\Delta\dot{W}_D - \epsilon_1\Delta\dot{p}_m - \epsilon_1\Delta\dot{p}_T} \tag{98}$$

$$ic_D^m = \frac{\overline{ic}_D^m}{1 + \epsilon_0\Delta\dot{p}_m - \epsilon_1\Delta\dot{W}_D - \epsilon_1\Delta\dot{p}_T} \tag{99}$$

$$ic_D^T = \frac{\overline{ic}_D^T}{1 + \epsilon_0\Delta\dot{p}_T - \epsilon_1\Delta\dot{W}_D - \epsilon_1\Delta\dot{p}_m} \tag{100}$$

The explanation for this formulation was already provided in the previous subsection. Again, once intermediate inputs are determined, it is possible to set prices as an exogenous mark-up η_D over unitary costs:

$$p_D = (1+\eta_D)\frac{(W_D N_D + IC_D^T + IC_D^m)}{s_D} \tag{101}$$

The last part of the sector that needs to be described is the distribution of profits. Firms' profits before taxes are:

$$F_D = S_D - W_D N_D - IC_D^T - IC_D^m - i_{D_{-1}} L_{D_{-1}} \tag{102}$$

Where $i_{D_{-1}} L_{D_{-1}}$ is interest payments on corporate debt.

Profits are then allocated as follows. Part of them goes into taxes $T_D = t_f F_D$. Moreover, firms retain a share of profit F_D^u equal to an exogenous share ϑ_D of nominal investment INV_D:

$$F_D^u = \vartheta_D INV_D \tag{103}$$

Another exogenous share Θ_D of profits is devoted to R&D:

$$\mho_D = \Theta_D F_D \tag{104}$$

Then, the residual part of profits is distributed:

$$F_H^D = F_D - T_D - F_D^u - \mho_D \tag{105}$$

Lastly, firms of the non-traded sector borrows from banks in order to cover the part of investment that is not financed by undistributed profits:

$$L_D = INV_D + L_{D_{-1}} - F_D^u \tag{106}$$

4.3 Resource sector

The resource sector is a more sophisticated version of that in Naqvi and Stockhammer (2018). In line with their work, its structure is simplified to improve the tractability of the model. Resources are extracted using capital bought from the traded sector. The resource sector does not have productive inputs such as labour or intermediate goods and does not borrow money from the banking sector. Its investments are completely self-financed. Real and nominal resource sales are r_R and R respectively:

$$r_R = r_T \tag{107}$$

$$R = p_R r_R \tag{108}$$

Where r_T is the demand for resource of the domestic traded sector and has been explained in equation 67. The traded sector is the only sector that directly purchases resources. Nominal sales of resources R are obtained by multiplying real sales times the price of resources p_R. The resource sector does not use labour or intermediate inputs, hence its price is determined as an exogenous mark-up η_R over an internal unitary cost Φ:

$$p_R = (1 + \eta_R)\Phi_{\mathrm{R}} \tag{109}$$

Where Φ_{R} starts as an exogenous value as in Naqvi and Stockhammer (2018). However, in this model its growth rate follows a simple adjustment process based on the inflation rate of the domestic price index:

$$\dot{\Phi}_R = \dot{\Phi}_{R_{-1}} + \Psi_{\mathrm{R}}\left(\dot{p}_{ds} - \dot{\Phi}_{R_{-1}}\right) \tag{110}$$

$\Psi_{\mathrm{R}} < 1$ is the exogenous adjustment parameter. Equation 110 ensures that the price of resources grows in line with the inflation rate of other prices. Without this formulation, p_R would remain stable in the steady state while the prices of the other goods would grow steadily.

The modelling of investment and capital accumulation is identical to that of standard SFC models (Godley and Lavoie, 2007). The target capital is not dependant on profits as in the traded and non-traded sectors. Adding profits as a determinant of the resource sector does not really affect the results of the model, thus keeping the sector simpler and with less exogenous parameters has been preferred. The target capital is determined as lagged real sales divided by the exogenously determined capital-to-output ratio κ:

$$\bar{k}_R = \frac{r_{-1}}{\kappa} \tag{111}$$

Real investment inv_R is then computed again following a partial adjustment investment function:

$$inv_R = \mu_k\left(\bar{k}_R - k_{R_{-1}}\right) + \delta k_{R_{-1}} \tag{112}$$

Real investment is added to the real capital stock k_R through equation 113:

$$k_R = (1 - \delta)k_{R_{-1}} + inv_R \tag{113}$$

New capital is bought from the traded sector, hence nominal gross investment and nominal capital stock are:

$$INV_R = p_T inv_R \tag{114}$$

$$K_R = (1 - \delta)K_{R_{-1}} + INV_R \tag{115}$$

It is worth pointing out that the resource sector itself cannot become more or less productive. Its only ‘productivity’ is the output-capital ratio κ, which is exogenous. Therefore, it does not play a role in improving resource efficiency, which mainly relies on improvement in the resource use of the traded sector.

The resource sector finances its investment entirely with own funds F_R^u. It does not have other costs apart from taxes on its gross profits T_R and the remaining part of its profits is distributed to households F_H^R. Hence:

$$F_R^u = INV_R \tag{116}$$

$$T_R = t_f R \tag{117}$$

$$F_H^R = R - F_R^u - T_R \tag{118}$$

5 Financial sectors

Having presented the production sectors, we now turn to the financial side of the model. Though every sector is involved in it, financial activities in this theoretical economy revolve around the banking sector and the central bank. We firstly introduce the banking sector in Subsection 5.1 and then present the central bank in Subsection 5.2.

5.1 Banking sector

In the PADME model, the banking sector plays the crucial role of providing credit to the productive sectors and the government. It also holds the accumulated wealth of households in the form of deposits. To meet its liquidity requirement, it keeps a certain level of reserves at the central bank account. The banking sector purchases bonds from the foreign government, hence it is the only sector which deals with international financial flows.

Banks here are simplified in their cost structure if compared to traded and non-traded firms. Specifically, banks do not employ workers, other inputs or capital. Their only costs are constituted by interest payments on deposits. They save part of their profits as a capital buffer. The remaining profits are distributed to households.

We first introduce the balance-sheet side of the banking sector. As mentioned above, the investable wealth of households is held in the form of deposits D on the liability side of banks. Thus:

$$D_B = D_H \tag{119}$$

On their asset side, banks requires a certain level of reserves HH_B to ensure that they have enough liquidity for their customers, this is determined as an exogenous share ρ over deposits:

$$HH_B = \rho D_B \tag{120}$$

Reserves are provided by the central bank. A description of reserves and their interest rate is provided in the next subsection.

Another category of assets that banks hold on their balance sheet is loans to firms. By assumption, banks always accommodate firms' needs for new loans, thus the total supply L_B^s is equal to:

$$L_B^s = L_T + L_D \tag{121}$$

Moreover, banks purchase domestic and foreign government bonds. The latter variable is particularly difficult to model. Indeed, international capital flows are not homogenous as they include many different types of assets and are driven by public and private investors with different incentives (Koepke, 2019). Here, the demand for foreign bonds is simply modelled as an exogenous share ϕ of their lagged total assets:

$$B_{BN}^{Sd} = \phi ASSETS_{-1} \tag{122}$$

where $ASSETS_{-1} = L_{B_{-1}}^s + HH_{B_{-1}} + B_{B_{-1}}^d + B_{BN_{-1}}^{Sd}$. This is not a realistic specification of demand for international assets, but it is useful as a starting point. More sophisticated formulations can be easily developed but would complicate the analysis and make the core dynamics of the model less clear.

The demand for domestic government bonds is determined as a residual to ensure the consistency of the banking sector's balance sheet:

$$B_B^d = B_{B_{-1}}^d + \Delta D_B^s + \Delta OF_B - (\Delta L_B^s + \Delta HH_B + \varepsilon_N \Delta B_{BN}^{Sd}) \tag{123}$$

where OF_b is banks' own funds. First differences must be used to account for potential capital gains due to fluctuations in the Northern exchange rate $\varepsilon_N = \frac{North\ currency}{South\ currency}$ and thus ensure the stock-flow consistency of the model (Godley and Lavoie, 2007).

Having described the balance sheet of the banking sector, we next turn to its financial flows. Banks' profits are the difference between all interest payments received on their assets and interest payments on their liabilities:

$$F_b = i_{g_{-1}} B_{B_{-1}}^s + \varepsilon * i_{g_{-1}}^S B_{BN_{-1}}^{Ss} + i_{T_{-1}} L_{T_{-1}} + i_{D_{-1}} L_{D_{-1}} + i_{hh_{-1}} HH_{B_{-1}} - i_{d_{-1}} D_{B_{-1}} \tag{124}$$

All interest rates are endogenous. Interest rates on reserves and government bonds are explained in Subsection 5.2. Banks control the interest rates on deposits i_d and firms' loans (i_T, i_D). The former is determined as a simple exogenous mark-up η_d over the lagged interest rate on reserves:

$$i_d = i_{hh_{-1}} + \eta_d \tag{125}$$

The lag is due to the robust finding that banks sluggishly adjust the deposit rate to changes in monetary policy (Gropp *et al.*, 2014; Horváth and Podpiera, 2012).

The interest rates on loans are obtained by adding an endogenous mark-up over the policy rate. In line with the evidence on the determinants of banks' interest rates (Gregor *et al.*, 2021), the mark-ups are dependent on the creditworthiness of the sector. The equations for firms' interest rates are:

$$i_T = i_{hh} + \eta_B^T \tag{126}$$

$$i_D = i_{hh} + \eta_B^D \tag{127}$$

Though it would be more logically consistent to use the deposit rate as the base of the mark-up, the policy rate i_{hh} was chosen given that empirical evidence shows that mark-ups on loans tend to react more quickly than mark-ups on deposits when the policy rate changes (Gropp *et al.*, 2014). η_B^T and η_B^D are based on the leverage ratio of the two sectors:

$$\eta_B^T = \eta_0 + \begin{cases} \eta_1 & if \quad \eta_2 * \frac{L_T}{F_T} < \eta_1 \\ \eta_2 * \frac{L_T}{F_T} & if \quad \eta_1 < \eta_2 * \frac{L_T}{F_T} < \eta_3 \\ \eta_3 & if \quad \eta_2 * \frac{L_T}{F_T} > \eta_3 \end{cases} \tag{128}$$

$$\eta_B^D = \eta_0 + \begin{cases} \eta_1 & if \quad \eta_2 * \frac{L_D}{F_D} < \eta_1 \\ \eta_2 * \frac{L_D}{F_D} & if \quad \eta_1 < \eta_2 * \frac{L_D}{F_D} < \eta_3 \\ \eta_3 & if \quad \eta_2 * \frac{L_D}{F_D} > \eta_3 \end{cases} \tag{129}$$

Where η_0, η_1, η_2 and η_3 are exogenous parameters and $\frac{L_T}{F_T}$ and $\frac{L_D}{F_D}$ are total loans over gross profits of the respective sectors. The structure of the equations above means that there is an upper and lower threshold for one-period changes in the mark-up on interest rates on loans. In other words, the interest rate on loans always changes following the policy rate, but if one firm sector becomes less (more) financially sound, the mark-up on its loans will not increase more than η_3 (decrease less than η_1) in that period. This choice is useful to avoid big fluctuations of the mark-up that could undermine the stability of the model. Apart from the modelling convenience, it is reasonable to expect that banks will revise their mark-up without making sudden large changes as they are subject to a competitive environment.

The choice of specifying the mark-up as dependant on $\frac{L_T}{F_T}$ stems from the literature on interest rate margins. There is a vast and complex body of work on this topic. Several factors affect banks' mark-up, such as institutional frameworks, competition, credit risk (Gregor *et al.*, 2021; Gropp *et al.*, 2014). Here, for the sake of simplicity, we focus on credit risk and use total debt over gross profit $\frac{L_T}{F_T}$ as its proxy variable.

Once banks' profits F_B are determined, banks allocate a share of them to their own capital, called 'own funds' here. Banks have a target level of own funds $\overline{OF}$ that they want to reach, which is an exogenous share τ of loans:

$$\overline{OF} = \tau L_B^s \tag{130}$$

Their actual own funds are then:

$$OF_B = F_B^u + OF_{B_{-1}} \tag{131}$$

Where F_{ub} is undistributed profits and — for the sake of simplicity — its formulation guarantees that OF_B is always equal to $\overline{OF}$:

$$F_B^u = \overline{OF} - OF_{B_{-1}} \tag{132}$$

The remaining profits are distributed to households:

$$F_H^B = F_B - F_B^u \tag{133}$$

5.2 The central bank

The central bank is the last sector that needs to be described. It has two functions: providing reserves to the banking sector and setting the interest rate on them. This interest rate serves as direct or indirect foundation for the other interest rates in the economy. Reserves are introduced into the system by purchasing government bonds. Hence, the balance sheet of the central bank has reserves on the liability side:

$$HH_{CB} = HH_B \tag{134}$$

The supply of reserves is equal to its demand coming from the banking sector. An equal amount of domestic government bonds is purchased and held on the asset side:

$$B_{CB}^d = HH_{CB} \tag{135}$$

In this way, the consistency of central bank's balance sheet is guaranteed.

Lastly, the central bank sets the interest rate on reserves following a heuristic similar to a Taylor rule:

$$i_{hh} = \begin{cases} i_{hh_{-1}} + (\iota_1 * \Delta\dot{p}_{ds}) & if \quad \dot{p}_{ds} < 1.5\% \\ i_{hh_{-1}} & if \quad 1.5\% \geq \dot{p}_{ds} \leq 2.5\% \\ i_{hh_{-1}} + (\iota_0 * \Delta\dot{p}_{ds}) & if \quad \dot{p}_{ds} > 2.5\% \end{cases} \tag{136}$$

Where ι_0 and ι_1 are exogenous parameters that represent the sensitivity of the monetary authority when inflation rate goes above or below its target respectively. The bigger the change, the more vigorously the central bank changes the interest rate to tame inflation. Equation 136 reflects the idea that the monetary authority has a corridor of acceptable values for the inflation rate (Castro, 2011; Martin and Milas, 2004). As long as inflation is within those values, the central bank does not change the interest rate on reserves.

It is worth reflecting here on what the role of interest rates is in this model and how effective monetary policy can be in targeting inflation. It is usually assumed that changes in interest rate impact aggregate demand. In this model, interest rates affect consumption through equation 4 and investment (equations 45 and 79) through their impact on firms' profits (equations 69 and 102). Hence, aggregate demand is negatively affected by a rise in the policy rate. However, the effect is limited to the short run and in the long run the inflation rate is not significantly influenced by interest rates. Interest rates here play a bigger role in shaping the dynamics of income distribution rather than directly influencing aggregate demand. Overall, the standard view that monetary policy can control inflation is not replicated in the PADME model. The central bank can use the interest rate to smooth the impact of a shock to the economy but cannot really bring inflation to a specific target level. Admittedly, not all the transmission channels identified in the literature have been replicated in PADME (Buch *et al.*, 2019; Hannsgen, 2007). Adding further channels might increase the importance that interest rate policies have on the results of the model.

The remaining interest rate that needs to be described is that on government bonds. In the PADME model, this is simply determined as an exogenous mark-up η_g over the policy rate:

$$i_g = i_{hh} + \eta_g \tag{137}$$

One criticism to this formulation of the interest rate on government bonds is that it does not consider the effects that market forces and central bank operations can have on the value of the mark-up. In this first version of the model, these are not included to avoid adding too many interactions among sectors. However, these dynamics could be considered for future research.

The last equation of the central bank sector regards its profits F_{CB}. These are the difference between interest inflows and outflows:

$$F_{CB} = i_{g_{-1}} B^{S}_{CB_{-1}} - i_{hh_{-1}} HH_{CB_{-1}} \tag{138}$$

F_{CB} is distributed to the government.

6 Labour market, trade and macroaggregates

This last section describes parts of the model that are not specific to a sector and thus have not been discussed in the previous sections. Subsection 6.1 presents the labour market, namely how employment and wages are determined. Subsection 6.2 provides a detailed description of how employment, wages and productivity are specified in the R&D module. Subsection 6.3 covers the variables related to the trade side of the model, such as the exchange rate, balance of payments, imports, exports and their respective prices. Lastly, Subsection 6.4 describes how certain macroeconomic aggregates are derived in the PADME model. These include GDP and the price index for domestic sales.

6.1 Labour market

The labour market in the PADME model is constituted by two employers, namely the traded and the non-traded sectors. Their demand for labour has been described above (equations 65 and 98). The maximum amount of available labour FE depends on the number of workers Q and the exogenously determined working hours wh:

$$FE = (wh) \cdot Q \tag{139}$$

The supply of labour Q and the employment rate E are:

$$Q = \begin{cases} Q_{-1} & if \quad E \leq E^{up} \\ \\ \dfrac{N}{E^{up} \cdot (wh)} & if \quad E > E^{up} \end{cases} \tag{140}$$

$$E = \frac{N}{Q} \tag{141}$$

Where E^{up} is an exogenous parameter and N is the total amount of workers ($N = N_T + N_D$). The meaning of equation 140 is that more workers enter the workforce when the employment rate is above its exogenous upper limit E^{up}, which is equal to 0.96 in our calibration (Appendix A, Section A.2).

The employment rate has a significant influence on real wages. Specifically, workers have a real wage target $\overline{w}$ that depends on the *average* level of labour productivity $\lambda_{av} = \frac{s_T+s_D}{N_T+N_D}$ and on the employment rate:

$$\ln{(\overline{w})} = \varpi_0 + \varpi_1 \ln(\lambda_{av}) + \varpi_2 \ln(E) \tag{142}$$

This formulation is taken from Jackson and Jackson (2021), who have modified the equation proposed by (Godley and Lavoie, 2007) in chapter 11 of their textbook. The choice of using the average level of labour productivity instead of labour productivity at the sector level is in line with empirical findings (Hartwig, 2011; Nordhaus, 2008), although conclusive evidence is still missing. The employment rate plays the role of a proxy for workers' bargaining power.

Nominal wages are then derived using a partial adjustment function:

$$W_D = W_{D_{-1}} + \varpi_3\left(\overline{w} * p_{ds} - W_{D_{-1}}\right) \tag{143}$$

$$W_T = W_{T_{-1}} + \varpi_3\left(\overline{w} * p_{ds} - W_{T_{-1}}\right) \tag{144}$$

p_{ds} is a price index that is described in the next subsection. $\varpi_3 < 1$ is an exogenous parameter.

6.2 R&D module

Wages and employment in the R&D sector are modelled in a simplified fashion. The rationale behind the formulation described here stems from a problem that affected the model when R&D income was not linked to real resources. In particular, in certain simulations the government could end up spending up to 20% of its budget in R&D activities, creating very high levels of productivity growth for all inputs. This was clearly unrealistic, hence the decision to link R&D expenditure to real variables. Indeed, once all researchers are employed, adding more income to R&D simply triggers inflation of researchers' wages without increasing R&D output. The supply of researchers adapts to higher demand for R&D, but this happens following a slow process of adjustment. This sluggish adjustment reflects a more realistic scenario where highly skilled workers are scarce and the training process for increasing their supply takes time.

Wages in the R&D module follow the inflation rate of the average wage in the economy, unless there is a shortage of researchers:

$$W_{R\&D} = \begin{cases} W_{R\&D_{-1}}(1+\dot{W}_{av}) & if \quad \frac{N_{R\&D}}{Q_{R\&D}} \leq 1 \\ \frac{\mho}{Q_{R\&D}} & if \quad \frac{N_{R\&D}}{Q_{R\&D}} > 1 \end{cases} \tag{145}$$

Where $N_{R\&D}$ is the number of researchers employed and $Q_{R\&D}$ is the total labour force for the R&D sector. In other words, when there is full employment in the R&D sector, the wage $W_{R\&D}$ increases until the demand for workers matches the labour force.

$Q_{R\&D}$ is constant unless full employment in R&D is reached, in which case it grows following the growth rate of R&D funding $\dot{\mho}$:

$$Q_{R\&D} = \begin{cases} Q_{R\&D_{-1}} & if \quad \dot{W}_{R\&D} \leq \dot{W}_{av} \\ Q_{R\&D_{-1}} + \Psi_{R\&D}\dot{\mho} & if \quad \dot{W}_{R\&D} > \dot{W}_{av} \end{cases} \tag{146}$$

$\Psi_{R\&D}$ is an exogenous parameter. $\dot{W}_{R\&D} > \dot{W}_{av}$ is another way to say that $Q_{R\&D}$ increases when full employment is reached. This alternative formulation is needed to avoid a circular argument in the model. The idea behind the equation 146 is that when there is a shortage of researchers, R&D wages increase more than the average wage growth and this attracts more workers, allowing for an expansion of R&D activities.

The number of people employed $N_{R\&D}$ is equal to the total R&D funds divided by the R&D wage:

$$N_{R\&D} = \frac{\mho}{W_{R\&D}} \tag{147}$$

Thus, it becomes clear what happens when full employment in the R&D module is reached, i.e., $\frac{N_{R\&D}}{Q_{R\&D}} > 1$. Basically, $W_{R\&D}$ becomes $W_{R\&D} = \frac{\mho}{Q_{R\&D}}$ which, once substituted in the above equation (147), yields $N_{R\&D} = \frac{\mho}{\frac{\mho}{Q_{R\&D}}} = Q_{R\&D}$.

Lastly, once the number of workers employed has been determined, we can derive the real R&D output. This depends on researchers' productivity, thus:

$$y_{R\&D} = \lambda_{R\&D} N_{R\&D} \tag{148}$$

Where researchers' productivity is growing at an exogenous growth rate $\lambda_{R\&D}$:

$$\lambda_{R\&D} = \lambda_{R\&D_{-1}}(1 + \lambda_{R\&D}^{gt}) \tag{149}$$

Once all of these variables have been derived, it is possible to compute the ratio between real R&D output and real GDP which will be used in the equations determining the input productivity growth rates (such as equations 60, 61 and 62):

$$RD_{ratio} = \frac{y_{R\&D}}{y} \tag{150}$$

6.3 Trade and exchange rate

In this subsection, we describe how the variables that represent international trade have been specified. We firstly present the equations of imports and exports. Next, we show how export and import prices are specified. Lastly, we outline how the exchange rate and the balance of payments are determined.

Real imports are derived as the sum of imported consumption and intermediate good requirements:

$$m = cons_H^m + g_H^m + ic_T^m + ic_D^m \tag{151}$$

Real exports are constituted by the same variables but of the other area. In this case, we just use the superscript x to identify them, but clearly from the perspective of the other area they are imports. Exports are produced by the traded sector, thus the subscript T:

$$x_T = cons_H^x + g_H^x + ic_T^x + ic_D^x \tag{152}$$

It is worth mentioning that capital is not traded in this model.

Nominal imports and exports are obtained by multiplying their real values by their respective prices:

$$M = p_m m \tag{153}$$

$$X = p_x x_T \tag{154}$$

As mentioned previously, the export price p_x is different from its base price p_T. Exporters do not decide the price of their exports solely in relation to the production costs. They also take into account the other country price p_T^S (namely competition) and the fluctuations in the foreign exchange rate $\varepsilon_S = \frac{1}{\varepsilon} = \frac{South\ currency}{North\ currency}$. This formulation is taken from (Godley and Lavoie, 2007) and allows to model pass-through effects:

$$\ln(p_x) = -\sigma_1 \ln(\varepsilon_S) + (1 - \sigma_1) \ln(p_T) + \sigma_1 \ln\left(p_T^S\right) \tag{155}$$

Where σ_1 is an exogenous coefficient that has an important role in the model. Suppose there is a depreciation of the foreign currency, thus ε_S increases. If $\sigma_1 = 0$, exporters do not take into account the exchange rate movement and any change in the foreign price. They maintain the price equal to p_T. In this way, they favour increases in their profits over increase in their market share. Conversely if $\sigma_1 = 1$, exporters prefer to focus on their sales and thus decrease their export price by the same amount of the increase in the exchange rate. In this way, no matter what the original value of p_T is, they will always change the export price to accommodate the fluctuations in the exchange rate.

The import price is the export price of the foreign country multiplied by the domestic exchange rate ε and the tariff rate t_m:

$$p_m = \varepsilon_N \, p_x^S t_m \tag{156}$$

p_x^S is specified in the same way as p_x (equation 155), but clearly the variables are now related to the South (hence the 'S' in the equation number):

$$\ln(p_x^S) = -\sigma_1^S \ln(\varepsilon_N) + \left(1 - \sigma_1^S\right) \ln\left(p_T^S\right) + \sigma_1^S \ln(p_T) \tag{155.S}$$

Lastly, the exchange rate is determined as:

$$\varepsilon_N = \frac{B_{BS}^{Ns}}{B_{BS}^{Nd}} \tag{157}$$

B_{BS}^{Ns} is the supply of Northern government bonds to foreign banks, which has been described in Subsection 3.2, equation 40. B_{BS}^{Nd} is Southern banks' demand for the Northern region's government bonds[4]. B_{BS}^{Ns} is denominated in the Northern currency, while B_{BS}^{Nd} is denominated in the Southern currency. Therefore, the logic of equation 157 is that when there is a discrepancy between demand B_{BS}^{Nd} and supply B_{BS}^{Ns}, the exchange rate adjusts to equalise the two.

Though it might seem that the exchange rate is only determined through the bond market, the interconnections of the SFC framework makes its determination entirely identical to more intuitive equations. For instance, the exchange rate could be derived as the ratio between the supply and demand of the domestic currency. Such formulation yields exactly the same results but introduces much more simultaneity in the determination of the exchange rate, which increases the likelihood of model crashes.

The balance of payments is represented by two equations. The current account balance (CAB) is computed as nominal exports X plus interest payments inflows $\varepsilon_N r_{g_{-1}}^S B_{BN}^{Ss}$ minus nominal imports M plus interest payments outflows $r_{g_{-1}} B_{BS}^{Ns}$:

$$CAB = \left(X + \varepsilon_N r_{g_{-1}}^S B_{BN}^{Ss}\right) - \left(M + r_{g_{-1}} B_{BS}^{Ns}\right) \tag{158}$$

4 It is identical to equation 122 but from the South perspective: $B_{BS}^{Nd} = \phi_0(ASSETS_{-1}^S)$

The financial account balance (KAB) is the difference between capital inflows ΔB_{BS}^{Ns} and capital outflows $\varepsilon \Delta B_{BN}^{Ss}$:

$$KAB = \Delta B_{BS}^{Ns} - \varepsilon \Delta B_{BN}^{Ss} \tag{159}$$

Where B_{BN}^{Ss} is the supply of South bonds to the banks in the North. By accounting necessity, the value of the financial account balance is always the opposite of the current account balance, $KAB = -CAB$.

6.4 Macroeconomic aggregates

This last subsection concludes the description of the model by presenting few equations that are used to compute aggregate values such as GDP at the country level and the price index. Some of these variables might not play a role in the dynamics of the model but are used when presenting its results, so it is worth mentioning how they are derived.

Real and nominal total output of one region are given by:

$$s = s_T + s_D + r_R \tag{160}$$

$$S = S_T + S_D + R_R \tag{161}$$

Real and nominal GDP can be computed from a production perspective and are:

$$y = s - ic_T^S - ic_D^S - ic_D^T - r_T \tag{161}$$

$$Y = S - IC_T^S - IC_D^S - IC_D^T - R_T \tag{162}$$

The material footprint in one region is:

$$r_{cons} = r_R - \frac{x}{\frac{s_T}{r_T}} + \frac{m}{\frac{s_{TS}}{r_{TS}}} \tag{163}$$

Namely, resources extracted minus resources exported plus resource imported. $\frac{s_{TS}}{r_{TS}}$ is resource productivity in the South, while $\frac{s_T}{r_T}$ is that in the North.

Lastly, we have defined all the prices in the economy, thus we can now describe the price index p_{ds} used to keep track of the price dynamics of domestic sales. This is a simple weighted average of the prices in one area for all the goods that are consumed or used by the different sectors:

$$p_{ds} = \frac{S_D + (S_T - X) + M + R}{s + m - x} \tag{164}$$

It is neither a GDP deflator nor a consumer price index (CPI). Indeed, it does not include prices of exports as the former, but it includes prices of investment goods and productive sectors' intermediate consumption, which are not included in the CPI. However, this is the most accurate index for the average prices that the economy faces at a given period in the PADME model.

A proper CPI could be derived as:

$$p_{CPI} = \frac{CONS_H^D + CONS_H^T + CONS_H^m}{cons_H} \tag{165}$$

This is usually the index of reference for the central bank when it has to set the policy rate. In this model, the central bank targets p_{ds} because it better reflects the dynamics of prices faced by all sector in the economy. This choice has a negligible effect on the results of the model, but it seems more theoretically consistent.

This last equation concludes the description of the model. The next two sections will cover some interesting post-growth policies that can be simulated in PADME.

7 Modelling a cap-and-trade scheme

In the Introduction section, we mentioned that the structure of the PADME model allows us to simulate a cap-and-trade scheme. This policy is interesting because it can be the central pillar of a post-growth transition (Leoni *et al.*, 2023). In particular, a decreasing cap on resources is able to target environmental sustainability explicitly without assuming a particular trajectory for GDP. Moreover, it offers a realistic narrative on how the post-growth transition would come about. Following the predominant view in the post-growth community that the developed world should start the transition while the developing world keeps developing (Hickel *et al.*, 2022; Jackson, 2009), we assume that the cap is implemented in the North, the region representing the global North in PADME.

The way in which the cap is modelled in PADME requires some further explanations and the introduction of a few new equations. Before delving into the technicalities of modelling this policy in a stock-flow consistent model, it is worth describing the core features of a cap-and-trade scheme.

A cap-and-trade scheme is a policy that aims to constrain the amount of aggregate production of a given resource or pollutant to a certain pre-defined level. In order to implement the cap, in any given period a limited number of 'allowances', i.e., a permit that allows the holder to consume a given quantity of resources, are issued by the regulatory authority and distributed to different economic actors depending on the authority's priorities. Producers of the resource can then trade these allowances in order that each producer is able to obtain a number of allowances equal to the quantity of resource that they want to produce. At the end of the period, allowances are handed over to the regulatory authority and a new round of issuance follows. The decision concerning the distribution of the allowances does not affect the results of the policy, but it has consequences which are relevant in terms of distributional effects (Stavins, 2008). For instance, if the government decides to auction the allowances, the revenue collected through the auctioning can be spent for other purposes. Conversely, giving free allowances to certain industries can be seen as a form of compensation for the negative effects that the cap might have on them.

The price of allowances has an important economic meaning. From a neoclassical economic perspective, it ensures that the externalities created by the production of resources are fully internalised, thus solving a market imperfection. The cost internalisation is then supposed to reestablish 'market efficiency'. From this perspective, the cap-and-trade system generates the optimal price for resources.

The level of aggregation of the PADME model does not allow for detailed modelling of the trade side of the policy. Thus, what happens in the model is that after the introduction of the cap, the price of resources increases until the demand for them is reduced enough to match the capped supply. The price of the allowances is then obtained as the difference between the original price of resource and the new price needed to equilibrate demand and supply. Once this difference is multiplied by the quantity of resources produced, we obtain the revenue generated by the introduction of the policy. If all this revenue is allocated to the government, then we can say that the allowances have been auctioned. If the revenue is allocated to a specific sector, then allowances have been freely distributed to that sector.

Subsection 7.1 shows the equations necessary to simulate the cap on domestic resources. Subsection 7.2 describes the way in which the cap on resources embedded in imports can be introduced in the model. Lastly, Subsection 7.3 briefly outlines how to derive the allowances income and model its allocation.

7.1 The cap on domestic resources

Several modifications to the PADME model are necessary to simulate the cap on domestic resource. The price of resources p_R needs to be modified to include the price of resource allowances t_r. In all the equations below, new variables that are added to pre-existing equations are highlighted in bold to improve the clarity of the exposition. Therefore, equation 109 becomes:

$$p_R = (1+\eta_R)(\mathbf{1}+\boldsymbol{t_r})\Phi_R \tag{166}$$

Where η_R is the exogenous mark-up and Φ_R are unit costs. As mentioned above, theoretically t_r plays the same role of a resource tax. However, while a resource tax sets a given rate and let the quantity adjust, a cap-and-trade scheme sets the quantity and let the rate adjust (Stavins, 2008). In other words, instead of being defined as a fixed rate applied to the price of resources, the value of t_r constantly adjusts to enforce the equality between the capped supply of resource $\hat{r}$ and its demand r_T. In order to obtain this value, we need to solve the following constraint for t_r:

$$r_T = \hat{r} \tag{167}$$

Which means that the demand for resources r_T must be equal to the capped supply of resources $\hat{r}$. Several mathematical steps are needed to explicitly show that this equality is dependent on t_r.

In order to solve equation 167 for t_R, we need to substitute r_T with equation 67, which determines the actual resource demand of the traded sector once substitution effects ($\epsilon_0 \Delta \dot{p}_R - \epsilon_1 \Delta \dot{W}_T - \epsilon_1 \Delta \dot{p}_m$) are considered (see):

$$\boldsymbol{\hat{r}} = \frac{\boldsymbol{\bar{r}_T}}{\mathbf{1} + \boldsymbol{\epsilon_0} \Delta \boldsymbol{\dot{p}_R} - \boldsymbol{\epsilon_1} \Delta \boldsymbol{\dot{W}_T} - \boldsymbol{\epsilon_1} \Delta \boldsymbol{\dot{p}_m}} \tag{168}$$

Where $\bar{r}_T$ is the target demand for resource of the traded sector based on long-term productivity levels. ϵ_0 and ϵ_1 are exogenous parameters that regulate the sensitivity of substitution between inputs. $\dot{p}_R$, $\dot{W}_T$ and $\dot{p}_m$ are the inflation rates of the price of resources, labour and imports respectively. Equation 67 is important because it allows us to include prices in the determination of the demand for productive inputs. Once prices are explicitly included in the equation of $\hat{r}$, we can solve it for t_R. More precisely, we rewrite $\dot{p}_R = \frac{p_R - p_{R_{-1}}}{p_{R_{-1}}}$ and substitute it in equation 168:

$$\hat{r} = \frac{\bar{r}_T}{1 + \epsilon_0 \left[\left(\frac{\boldsymbol{p_R} - \boldsymbol{p_{R_{-1}}}}{\boldsymbol{p_{R_{-1}}}} \right) - \dot{p}_{R_{-1}} \right] - \epsilon_1 \Delta \dot{W}_T - \epsilon_1 \Delta \dot{p}_m} \tag{169}$$

Next, we substitute p_R with equation 166:

$$\hat{r} = \frac{\bar{r}_T}{1 + \epsilon_0 \left(\frac{(\mathbf{1} + \boldsymbol{\eta_R})(\mathbf{1} + \boldsymbol{t_R})\boldsymbol{\Phi_R} - \boldsymbol{p_{R_{-1}}}}{\boldsymbol{p_{R_{-1}}}} - \dot{p}_{R_{-1}} \right) - \epsilon_1 \Delta \dot{W}_T - \epsilon_1 \Delta \dot{p}_m} \tag{170}$$

Now, with few simple manipulations, we can isolate t_R on the left-hand side of the equation:

$$t_r = \frac{\left(\frac{\frac{\bar{r}_T}{\hat{r}} - 1 + \epsilon_1 \Delta \dot{W}_T + \epsilon_1 \Delta \dot{p}_m}{\epsilon_0} + \dot{p}_{R_{-1}}\right) p_{R_{-1}} + p_{R_{-1}}}{(1+\eta_R)\Phi_\mathrm{R}} - 1 \qquad (171)$$

Where $\dot{W}_T$ is nominal wage growth rate, $\dot{p}_m$ is the growth rate of import prices and ϵ_0 and ϵ_1 are the exogenous parameters that regulate the substitutability between productive inputs (see equation 67). The above equation allows the variable t_r to equalise the demand for resources with its capped supply. In the PADME model, the actual equation for t_r is:

$$t_r = \begin{cases} t_{r_{-1}} & if \quad \hat{r} \geq r_T \\ \dfrac{\left(\frac{\frac{\bar{r}_T}{\hat{r}} - 1 + \epsilon_1 \Delta \dot{W}_T + \epsilon_1 \Delta \dot{p}_m}{\epsilon_0} + \dot{p}_{R_{-1}}\right) p_{R_{-1}} + p_{R_{-1}}}{(1+\eta_R)\Phi_\mathrm{R}} - 1 & if \quad \hat{r} < r_T \end{cases} \qquad (172)$$

In other words, as long as the cap-and-trade policy is not introduced, $t_r = t_{r_{-1}}$, namely, t_r is equal to its past value, which is initially zero.

7.2 The cap on resources embedded in imports

Importantly, the cap must be implemented both on domestic resource consumption in the North and on Northern imports[5]. The cap on resources embedded in imports is crucial to avoid inconsistencies. Indeed, the introduction of a cap on domestic resource consumption in the North alone would have the perverse effect of leading to the outsourcing of resource extraction to the South.

Capping imports follows a similar process to that shown for domestic resource production. In this case, the tariff rate t_m plays the crucial role of reducing the demand for imports m until it matches the capped supply. The only difference is that the cap is not directly on resources but on resources embedded in imports r_m. Embedded resources in imports r_m are obtained by dividing the quantity of real imports in the North m by resource productivity of the traded sector in the South π^S:

5 In the closed-economy version of PADME, the cap on resources embedded in imports is clearly not present.

$$r_m = \frac{m}{\pi^S} \tag{173}$$

Where $\pi^S = \frac{s_T^S}{r_T^S}$, i.e., the resource productivity of the Southern traded sector is the ratio between its real output s_T^S and its consumption of resources r_T^S.

Like the price of allowances t_r, the tariff rate t_m is the endogenous variable that must adapt to guarantee the equality between (resource embedded in) capped imports $\hat{r}_m$ and their demand r_m. In other words, we have to solve the following equality for t_m:

$$r_m = \hat{r}_m \tag{174}$$

Given that $r_m = \frac{m}{\pi^S}$, namely resources embedded in imports are equal to real imports m divided by resource productivity in the South π^S (equation 173), we can rewrite equation 174 as:

$$\hat{r}_m = \frac{\boldsymbol{m}}{\boldsymbol{\pi^S}} \tag{175}$$

Real imports m can be substituted with equation 151, thus:

$$\hat{r}_m = \frac{\boldsymbol{cons_H^m + g_H^m + ic_T^m + ic_D^m}}{\pi^S} \tag{176}$$

Household and government real consumption of imports $cons_H^m$ and g_H^m can be substituted with equations 11 and 26 respectively:

$$\hat{r}_m = \frac{\frac{\boldsymbol{CONS_H^m}}{\boldsymbol{p_m}} + \frac{\boldsymbol{G^m}}{\boldsymbol{p_m}} + ic_T^m + ic_D^m}{\pi^S} \tag{177}$$

Equation 177 shows why deriving real consumption from nominal values $CONS_H^m$ and G^m is necessary to model the cap. Indeed, this formulation allows us to start from the equality in equation 174 and reach equation 177, where the price of imports p_m is explicitly included. This is crucial because the equation that determines p_m (156) is dependent on the tariff rate t_m. In other words, after substituting equation 156 in equation 177, we can solve $\hat{r}_m$ for the tariff rate t_m. Indeed:

$$\hat{r}_m = \frac{\frac{CONS_H^m}{\boldsymbol{\varepsilon_N\, p_x^S t_m}} + \frac{G^m}{\boldsymbol{\varepsilon_N\, p_x^S t_m}} + ic_T^m + ic_D^m}{\pi^S} \tag{178}$$

Once equation 178 is rearranged to isolate the tariff rate t_m on the left-hand side, we obtain the necessary condition to ensure that the demand for imported resources matches the capped supply via adjustments in the tariff rate:

$$t_m = \frac{CONS_H^m + G^m}{(\hat{r}_m \pi^S - ic_T^m - ic_D^m)\varepsilon_N \, p_x^S} \tag{179}$$

Where $CONS_H^m$ and G^m are consumption of imported goods by Northern households and government respectively, ic_T^m and ic_D^m represent the imported intermediate consumption of the traded and non-traded sectors respectively and $\varepsilon_N \, p_x^S$ is the Northern exchange rate times the export price set by Southern exports. Basically, equation 179 means that if the demand for imports exceeds the capped supply, the tariff rate t_m increases until the former is equalised to the latter.

It is worth reiterating here that the equation for t_m can be derived only thanks to consumption being modelled starting from nominal values (Section 3). Specifically, this approach to determining consumption makes the equality in equation 174 dependant on t_m as shown above.

The actual equation of the tariff rate in the model is:

$$t_m = \begin{cases} t_{m_{-1}} & if \quad \hat{r}_m \geq r_m \\ \dfrac{CONS_H^m + G^m}{(\hat{r}_m \pi^S - ic_T^m - ic_D^m)\varepsilon_N \, p_x^S} & if \quad \hat{r}_m < r_m \end{cases} \tag{180}$$

That is, as long as the cap on imports is not introduced, $\hat{r}_m$ is bigger than r_m and thus t_m is equal to its past values, which is one in the steady state of the baseline model (therefore the actual tariff rate is zero, see equation 35).

The last addition to the model is the inclusion of two conditional variables: $activate_r$ and $activate_m$. Their starting value is zero. When the modeller assigns them the value of 1, the cap on resources and on imports are respectively activated.

The next subsection shows how we can isolate the allowances income once the cap is working.

7.3 Allowances income and its allocation

Once the cap starts functioning, the income derived from the allowances can be isolated as the income coming from the regulation of domestic resources T_r and the one coming from the regulation of imports T_m. Specifically, the equation that allows to compute the former is:

$$T_r = t_r(1 + \eta_R)\Phi_R r_R \tag{181}$$

Where t_r is the price of allowances and $(1+\eta_R)\Phi_R r_R$ is the nominal sales of resources. In other words, the income collected through the resource allowances is equal to the quantity of resources sold times the price of allowances — which, as explained above, can be interpreted as a tax rate.

Similarly, the income collected through the cap on imports T_m is equal to the tariff rate $(t_m - 1)$ times nominal imports $\varepsilon_N\, p_x^S m$:

$$T_m = \varepsilon_N\, p_x^S m(t_m - 1) \tag{182}$$

The way in which these two incomes are spent depends on the design of the cap-and-trade, which is ultimately decided by the priorities of the policymaker. For instance, the government could auction all the allowances and use that income to repay its public debt or finance more research in resource efficiency. Alternatively, the government could decide to distribute the allowances to certain sectors for free, which is conceptually identical to transferring part of the income above to those sectors.

It is worth showing how the model needs to be modified to allow for the distribution of the allowances income to the firm sectors. First, we need to introduce an exogenous parameter ℓ_0. The sum of the tax income collected through the tariff T_m and the cap T_r can be defined as: $T_{cap} = T_r + T_m$. From T_{cap}, we can obtain the subsidy given to the firm sectors Sub_{tot} as:

$$Sub_{tot} = \ell_0 T_{cap} \tag{183}$$

The value of ℓ_0 can be interpreted as the share of allowances income that the government is willing to freely distribute to the private sector.

Next, the subsidy is divided among the three sectors by the exogenous parameters ℓ_T, ℓ_D, ℓ_R:

$$Sub_T = \ell_T Sub_{tot} \tag{184}$$

$$Sub_D = \ell_D Sub_{tot} \tag{185}$$

$$Sub_R = \ell_R Sub_{tot} \tag{186}$$

The sector-specific subsidies are then added (in bold) to the gross profits F_T, F_D and R (equations 69, 102 and 108) of the traded, non-traded and resource sector respectively:

$$F_T = S_T - W_T N_T - IC_T^m - R_T - i_{T_{-1}} L_{T_{-1}} + \boldsymbol{Sub_T} \tag{187}$$

$$F_D = S_D - W_D N_D - IC_D^T - IC_D^m - i_{D_{-1}} L_{D_{-1}} + \boldsymbol{Sub_D} \tag{188}$$

$$R = p_R r_R (1 - t_r) + \boldsymbol{Sub_R} \tag{189}$$

Where F_T and F_D are computed as the difference between nominal sales (S_T and S_D) and the cost of productive input plus interest payments

$(i_{T_{-1}} L_{T_{-1}}, i_{D_{-1}} L_{D_{-1}})$. R is simply the revenue of the resource sector $p_R r_R$ minus the cost of allowances t_r.

8 Modelling cooperative international policies

The PADME model is able to show cooperative policies between the two regions. In particular, we model two transfers that can be implemented by the North to help the South in coping with the new macroeconomic environment generated by the North's post-growth transition. Subsection 8.1 describes how we modelled a financial transfer to improve the financial sustainability of the South. Subsection 8.2 shows a technology transfer aimed at speeding up the technological development of the South.

8.1 Financial transfer

The financial transfer in the PADME model is designed to assist the Southern government in dealing with the financial imbalances generated by the post-growth transition in the North. Specifically, the North wants to ensure that the public finances of the South remains sustainable. Therefore, the former transfer money to the latter when the Southern public debt-to-GDP ratio reaches the threshold that would trigger austerity measures (see Section 3). The North then provides enough funding to the Southern government to keep the ratio below the austerity threshold, thus avoiding the contraction of fiscal spending and allowing the South to pursue economic development. Clearly, this is only a modelling construction and might not be replicable in the real world. Indeed, it is unlikely that the developed world will target a specific level of debt for the countries in the South. More likely, financial assistance would come from a variety of financial instruments. However, this is a useful modelling construct to show the importance of financial cooperation.

In order to finance the transfer, the Northern government can use a share of the income collected through the tariff rate implemented for capping imports. This would be ethically reasonable as the tariff rate undermines Southern exports. Hence, giving to the South part of the money collected through the import cap would avoid framing the tariff as an unfair punishment for the Southern economy.

From a modelling perspective, introducing this international transfer requires adding a new variable IT in the model. This is defined as an endogenous share Π of the tariff income T_m:

$$IT = \Pi T_m \tag{190}$$

The variable IT has to be added to equation 37 (hence it is highlighted in bold, see previous section), which determines the demand for new government bonds B^{Ns}:

$$B^{Ns} = \left(G_{tot}^{N} + B_{-1}^{Ns} + i_{g_{-1}}^{N} B_{-1}^{Ns}\right) - \left(T^{N} - \boldsymbol{IT} + F_{CB}^{N}\right) \tag{191}$$

$$B^{Ss} = \left(G_{tot}^{S} + B_{-1}^{Ss} + i_{g_{-1}}^{S} B_{-1}^{Ss}\right) - \left(T^{S} + \varepsilon_S \boldsymbol{IT} + F_{CB}^{S}\right) \tag{191.S}$$

Where G_{tot}^{N} is government spending, B_{-1}^{Ns} is the lagged stock of government bond supplied by the Northern government, $i_{g_{-1}}^{N} B_{-1}^{Ns}$ are interest payments, T^{N} is total tax income and F_{CB}^{N} is central bank's profits. The second equation represents the same variables but for the South (hence the 'S' in the equation number). Adding IT to both equations but with an opposite sign reflects the nature of the financial transfer from the North to the South.

The endogenous parameter Π is crucial to determining the actual amount of finance that is transferred every period. Specifically, it is modelled to ensure that the threshold of the debt-to-GDP ratio $\overline{Debt}$, which would start the austerity plan in the South, is never reached. Its equation is thus specified in order to solve the following constraint:

$$\frac{B^S}{Y^S} = \overline{Debt} \tag{192}$$

In other words, the public debt-to-GDP ratio of the South $\frac{B^S}{Y^S}$ has to be equal to the threshold level $\overline{Debt}$. With some simple substitutions and rearranging of variables[6], we can obtain from equation 192 the following equation:

$$\Pi = \frac{(G^S + iB_{-1}^{S} + B_{-1}^{S}) - (\overline{Debt}Y^S + T^S + F_{CB}^{S})}{\varepsilon_S T_m} \tag{193}$$

Which guarantees that the equality in equation 192 is respected. Lastly, we introduce a conditional operator to make sure that the transfer happens only when $\frac{B^S}{Y^S} \geq \overline{Debt}$:

$$\Pi = \begin{cases} 0 & if \quad \frac{B^S}{Y^S} < \overline{Debt} \\ \frac{(G^S + iB_{-1}^{S} + B_{-1}^{S}) - (\overline{Debt}Y^S + T^S + F_{CB}^{S})}{\varepsilon_S T_m} & if \quad \frac{B^S}{Y^S} \geq \overline{Debt} \end{cases} \tag{194}$$

Having described the modelling mechanism through which we can simulate the international transfer, we can now connect the technical part with a

6 We replace B^S with equation 191.S and obtain: $\frac{\left(G_{tot}^{S}+B_{-1}^{Ss}+i_{g_{-1}}^{S}B_{-1}^{Ss}+\varepsilon_S \boldsymbol{IT}\right)-\left(T^S+F_{CB}^{S}\right)}{Y^S} = \overline{Debt}$. Next, we replace IT with equation 190: $\frac{(G_{tot}^{S}+B_{-1}^{Ss}+i_{g_{-1}}^{S}B_{-1}^{Ss}+\varepsilon_S \Pi \boldsymbol{T_m})-(T^S+F_{CB}^{S})}{Y^S} = \overline{Debt}$. By rearranging this equation, we obtain the equation for Π.

more narrative description of the policy. The first important point, briefly mentioned above, is that the way in which the policy works is not meant to be realistic, for there are no fixed thresholds for debt sustainability in the real world and governments wouldn't transfer money to other countries to keep their debt-to-GDP ratio perfectly stable. Moreover, the North-South cooperation would include a set of different policies such as more allocation of grants to the South, forgiveness of larger shares of outstanding debt for highly indebted countries, more generous extensions of concessional loans to developing countries, less strict conditions attached to climate funding. However, this modelling approach allows us to metaphorically represents what would happen if the North was actively helping the South in dealing with its fiscal and financial sustainability. Our policy can thus be seen as an attempt to develop a proposal along the line suggested by Fenton et al. (2014), that is, including debt relief programmes in the discussion on global climate finance.

A further limitation of this modelling approach is that the financial transfer is denominated in Southern currency. This is inevitable as there is no foreign-denominated debt in the model. However, in the real world we would expect developed countries to transfer dollars to the developing world, as this currency provides a reliable means to access international commodity and financial markets. Moreover, dollar-denominated debt is often a key source of financial fragility and instability in developing countries, as a sudden lack of access to dollar financing risks severely hindering the ability of those nations to repay their foreign-denominated debt. Therefore, dollar transfers would probably constitute a major relief for many distressed low-income economies.

8.2 Technology transfer

A further cooperative policy that can be introduced in the PADME model is a technology transfer. This policy is an attempt to speed up the improvement in resource productivity of the South so that it can accelerate its transition towards a sustainable economy. Here, the technology transfer is modelled as a transfer of physical capital from the North to the South. Indeed, we have shown in Section 4 that technology is embedded in capital and thus that is the only way through which the higher resource and labour productivities embedded in Northern capital can be passed to the other region. In addition, we focus on the traded sector as this is the only sector in the model directly consuming resources. Importantly, the technology transfer can only work in the PADME model if the two regions are calibrated in such a way that their resource and labour productivities are different — with the North being technologically more advanced.

The technology transfer is partly financed through the direct transfer of money from the Northern government to the Southern traded sector in the form of grants and partly through a financial scheme inspired by the 'Climate Justice Facility' (CJF) proposal in Dafermos (2023). The financial scheme deserves more attention than the grants provided by the Northern government as its structure is quite sophisticated from a monetary perspective. We first describe our proposal and then explain how it differs from the original idea in Dafermos (2023).

Figure 4 provides a graphical illustration of how the scheme works. The Northern central bank purchases interest-free perpetual bonds issued by the Southern central bank by creating new money. The Southern central bank lends this money to the Southern traded sector in the form of interest-free perpetual loans. The Southern traded sector then purchases the more productive Northern capital from the Northern traded sector. All of these transactions are made in the Northern currency as this is the currency that the Northern central bank can create. Moreover, it is a more realistic way to frame the technology transfer as the purchase of capital and technology would probably happen in dollars.

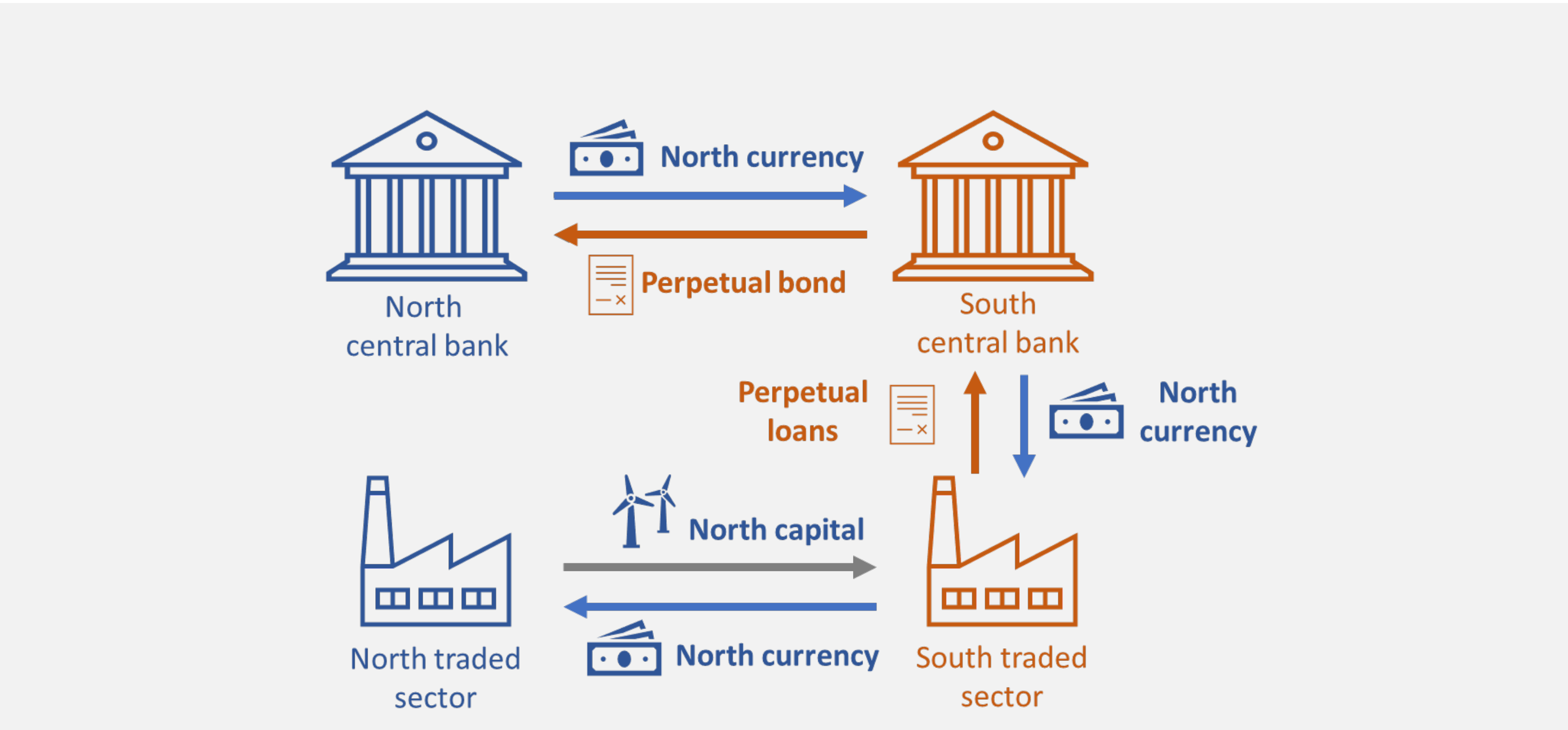

Figure 4: *Illustration of the scheme that relies on money creation to partially finance the technology transfer to the South: The Northern central bank purchases perpetual bonds issued by the Southern central bank through the creation of new money. This is then lent to the Southern traded sector in the form of perpetual loans. This sector uses the funding to buy the more productive Northern capital.*

Figure 5 illustrates and describes the changes to the balance sheet of the different actors involved in the financial scheme. The most notable aspect is that the reserves created by the Northern central bank end up being held by the Northern banking sector. Moreover, even if we show that the Northern traded sector is the last recipient of the money, the revenue gained by the Northern traded sector is either spent to pay input costs, taxes and interest on debt or is distributed as profits. Ultimately, these flows increase the net wealth of the Northern household sector, which is held in the form of deposits in the Northern banking sector. In other words, while the South accumulates productive, physical capital, the North accumulates financial wealth. These changes are shown in Appendix B for the balance sheet and transaction matrices.

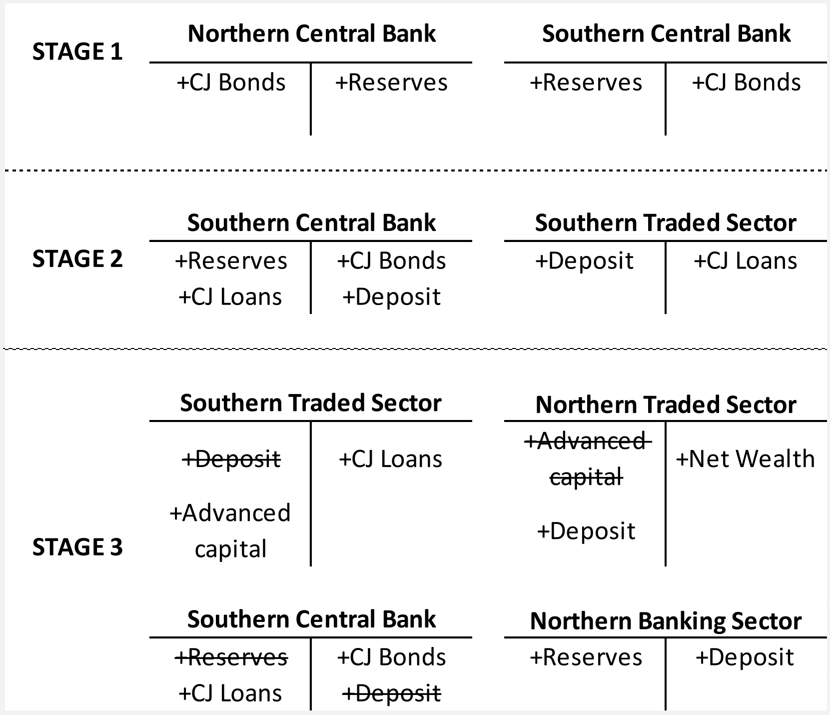

Figure 5: *Balance sheet changes resulting from the financial scheme developed to fund a share of the technology transfer.*

The following description of the changes in the balance sheet of the different sector includes realistic steps that are not necessarily simulated in the model.

STAGE 1. The Southern central bank issues Climate Justice (CJ) bonds that are bought by the Northern central bank through money creation. The creation of new money means that the Northern central bank injects new reserves in the monetary system by opening an account on its balance sheet for the Southern central bank.

STAGE 2. The southern central bank makes Climate Justice (CJ) loans to the Southern traded sector. This involves the southern central bank opening up 'deposit accounts' for the Southern traded sector denominated in northern currency on its balance sheet.

STAGE 3. The Southern traded sector purchases advanced capital from the Northern traded sector. This leads to a reduction in the balance of the Southern traded sector's deposit account at the Sothern central bank and an increase in the balance of the northern traded sector's deposit account with the northern banking sector. To facilitate this transaction, the Southern CB transfers an equivalent quantity of northern CB reserves to the northern banking sector.

Our policy differs from the original proposal in Dafermos (2023) in several ways. First of all, he advocates for the creation of an international fund, dubbed the 'Climate Justice Facility' (CJF), which would issue perpetual loans with zero or very low interest rates that would be purchased by the central banks of the developed world. The fund would then lend the money as perpetual loans to developing countries which are facing high economic damages as a result of climate change. In our model, given that there are only two regions, there is no need to introduce a new coordinating entity and we thus assume that the two central banks collaborate directly. Secondly, Dafermos suggests implementing the CJF to help developing countries that are facing high economic costs due to climate change. Instead, we model the financial scheme to finance the transfer of advanced capital to the South. While Dafermos' idea implies using the fund for idiosyncratic risks, we assume that this financial mechanism could be applied over much longer time horizons.

The modelling of the technology transfer requires several changes to the equations of the PADME model. Again, the variables that are added to preexisting equations are represented in bold characters to improve readability.

The total amount of funding TT that is provided to the South to purchase Northern capital is determined as an exogenous share υ_{TT} of real investment in the South inv^S multiplied by the price of the Northern capital p_T. This modelling choice allows us to target a value that is directly related to investment and thus avoids the risk of having too much or not enough capital flowing into the South. The equation is:

$$TT = \upsilon_{TT} \cdot p_T \cdot inv^S \tag{195}$$

A share of TT is financed through the income collected by auctioning the resource and import allowances in the North. Another share is funded by the Climate Justice (CJ) financial scheme described above. These two sources of financing prevent the overburdening of the Northern central bank balance sheet with perpetual bonds and simultaneously take some pressure off the Northern government finances. The split is exogenously determined by the parameter υ_{CJ}:

$$G_{TT} = (1 - \upsilon_{CJ})TT \tag{196}$$

$$CJ^s = \upsilon_{CJ}TT \tag{197}$$

Here CJ^s is the yearly supply of new bonds created by the Southern central bank while G_{TT} is the share financed by Northern tax income. G_{TT} is then added to the Northern government deficit equation 191:

$$B^s = \left(G_{tot} + B^s_{-1} + i_{g_{-1}}B^s_{-1}\right) - \left((T - IT - \boldsymbol{G_{TT}}) + F_{CB}\right) \tag{198}$$

Where $\left(G_{tot} + B^s_{-1} + i_{g_{-1}}B^s_{-1}\right)$ represents total government expenditure and include yearly government spending G_{tot}, the repayment of previous government debt B^s_{-1} and associated interest payments $i_{g_{-1}}B^s_{-1}$. $(T - IT - G_{TT}) + F_{CB}$ represents government inflows such as taxes T and central bank profits F_{CB}. G_{TT} (as well as IT as explained in the previous section) is recorded as a reduction in income for the government sector as the transfer of money is funded by allocating less tax revenue to repaying public debt.

The issuing of bonds CJ^s by the Southern central bank requires updating and adding several equations.

The stock of perpetual bonds issued by the Southern central bank is:

$$B^s_{CJ} = B^s_{CJ_{-1}} + CJ^s \tag{199}$$

The yearly supply CJ^s is matched with an equal demand CJ^d by the Northern central bank:

$$CJ^d = CJ^s \tag{200}$$

Similarly, the total stock of supplied bond is identical to the total stock of demanded bonds:

$$B^d_{CJ} = B^s_{CJ} \tag{201}$$

After receiving the money from the Northern central bank, the Southern central bank uses it to extend loans CJ^s_T to the Southern traded sector[7]. Accounting consistency requires that the supply of loans is equal to the supply of bonds:

$$CJ^s_T = CJ^s \tag{202}$$

7 In reality, the Southern banking sector would be the intermediary between the central bank and the traded sector, as firms cannot bank with the central bank directly. We adopt this approach here for the sake of simplicity. It is possible to add banks as intermediaries but it would not change the effects of the policy in any meaningful way.

The stock of these loans L^s_{CJ} is:

$$L^s_{CJ} = L^s_{CJ_{-1}} + CJ^s_T \quad (203)$$

The credit obtained by the Southern traded sector is represented as a demand for loans CJ^d_T and is equal to the supply of loans CJ^s_T:

$$CJ^d_T = CJ^s_T \quad (204)$$

The stock of demanded loans L^d_{CJ} is equal to the stock of supplied loans L^s_{CJ}:

$$L^d_{CJ} = L^s_{CJ} \quad (205)$$

The total amount of funding TT received each year through the Southern central bank CJ^d_T and the Northern government G_{TT} is used to purchase Northern capital inv_{TT} at its Northern price p_T:

$$inv_{TT} = \frac{TT}{p_T} \quad (206)$$

The equation determining the Southern total capital stock (equation 48) was previously specified as new investment inv^S_T plus the old capital stock $k^S_{T_{-1}}$ minus depreciation $\delta k^S_{T_{-1}}$. Now we add the new capital bought from the North inv_{TT}. Hence, equation 48 becomes:

$$k^S_T = (1-\delta)k^S_{T_{-1}} + inv^S_T + \boldsymbol{inv_{TT}} \quad (207)$$

The capital transferred from the North adds to the investment of the South inv^S_T and does not explicitly replace it. However, as the capital stock becomes bigger relative to sales, domestic investment is partly reduced. Overall, this effect is small because the boost in productivity provided by the Northern capital accelerates sales and output growth.

The purchase of capital by the Southern traded sector inv_{TT} has to be registered as new sales for the Northern traded sector. Thus, its real sales equation 41 changes to:

$$s_T = cons^T_H + g^T + ic^T_D + inv_T + inv_D + inv_R + x_T + \boldsymbol{inv_{TT}} \quad (202)$$

Where $cons^T_H + g^T + ic^T_D$ are the sales to the Northern domestic market, $inv_T + inv_D + inv_R$ are sales of capital goods and x_T represents exports.

Dafermos (2023) suggests making the perpetual bonds interest free in line with climate justice ethos. Nonetheless, we add an interest rate on CJ^s to increase the number of possible scenarios. The profits-before-tax equation 69 of the Southern traded sector is changed to take into account new interest payments $i_{CJ_{-1}}L^d_{CJ_{-1}}$:

$$F^S_T = S^S_T - W^S_T N^S_T - IC^{Sm}_T - R^S_T - i^S_{T_{-1}}L^S_{T_{-1}} - \boldsymbol{\varepsilon_S i_{CJ_{-1}} L^d_{CJ_{-1}}} \quad (208)$$

Where S_T^S is total nominal sales and $W_T^S N_T^S, IC_T^{Sm}, R_T^S$ are input costs (wages, intermediate goods and resources respectively) and $i_{T_{-1}}^S L_{T_{-1}}^S$ is interest payments on the debt stock of the sector.

Similarly, equation 138 — which determined the profits of the central bank — was previously computed as the difference between the inflows of interest payments on government bonds $i_{g_{-1}}^S B_{CB_{-1}}^{Ss}$ and the outflows of interest payments on reserves $i_{hh_{-1}} HH_{CB_{-1}}$. Now, the equation has to change so the Southern central bank includes interest payments received from the traded sector $\varepsilon_S i_{CJ_{-1}} L_{CJ_{-1}}^S$ and paid to the Northern central bank $\varepsilon_S i_{CJ_{-1}} B_{CJ_{-1}}^S$:

$$F_{CB}^S = i_{g_{-1}}^S B_{CB_{-1}}^{Ss} + \boldsymbol{\varepsilon_S i_{CJ_{-1}} L_{CJ_{-1}}^s} - i_{hh_{-1}} HH_{CB_{-1}} - \boldsymbol{\varepsilon_S i_{CJ_{-1}} B_{CJ_{-1}}^s} \quad (209)$$

Equation 138 of the Northern central bank was identical to that of the Southern central bank. Now, it has to include the interest payments received from the Southern central bank $i_{CJ_{-1}} B_{CJ_{-1}}^d$:

$$F_{CB} = i_{g_{-1}} B_{CB_{-1}}^S + \boldsymbol{i_{CJ_{-1}} B_{CJ_{-1}}^d} - i_{hh_{-1}} HH_{CB_{-1}} \quad (210)$$

Once these equations are in place, the value of the interest rate i_{CJ} can be changed to zero in order to replicate Dafermos' proposal.

Lastly, in the previous version of the PADME model, the central bank reserves were matched by an equal amount of government bonds on the asset side thanks to equation 135, which determined the central bank's demand for government bonds. Now that the Northern central bank holds a new type of asset, namely the perpetual bonds issued by the Southern central bank, equation 135 needs to adjust in order to ensure that total assets equalise total liabilities. Therefore, the demand for government bonds B_{CB}^d becomes equal to the total amount of reserves HH_{CB} minus the demand for perpetual bonds B_{CJ}^d:

$$B_{CB}^d = HH_{CB} - B_{CJ}^d \quad (211)$$

This set of changes ensures that the model is stock-flow consistent.

There is another change to the equations of the PADME model that is not directly related to stock-flow consistency. This concerns the way in which the input productivities of the South change as a result of the new Northern capital adopted for production. Equations 54 and 56 were used to compute the weighted average of the labour and resource productivity λ_T^S and π_T^S embedded in new and old capital. We have to add to this weighted average the new labour and resource productivities λ_{TT}^{new} and π_{TT}^{new} associated to the Northern capital inv_{TT}:

$$\lambda_T^S = \frac{\lambda_{T_{-1}}^S \left(k_{T_{-1}}^S - \delta k_{T_{-1}}^S\right) + \lambda_T^{Snew}\left(inv_T^S\right) + \boldsymbol{\lambda_{TT}^{new}(inv_{TT})}}{k_T^S} \quad (212)$$

$$\pi_T^S = \frac{\pi_{T-1}^S\left(k_{T-1}^S - \delta k_{T-1}^S\right) + \pi_T^{Snew}\left(inv_T^S\right) + \boldsymbol{\pi_{TT}^{new}}(\boldsymbol{inv_{TT}})}{k_T^S} \qquad (213)$$

Where $\lambda_{T-1}^S\left(k_{T-1}^S - \delta k_{T-1}^S\right)$ and $\pi_{T-1}^S\left(k_{T-1}^S - \delta k_{T-1}^S\right)$ represent labour and resource productivity respectively weighted by the old capital stock. $\lambda_T^{Snew}\left(inv_T^S\right)$ and $\pi_T^{Snew}\left(inv_T^S\right)$ represent new labour and resource productivity associated with new investment in Southern capital. Equations 54 and 56 only use these old and new productivities to compute the weighted average of labour and resource productivity (λ_T^S and π_T^S respectively) for the traded sector, while equations 212 and 213 include the Northern productivities λ_{TT}^{new} and π_{TT}^{new} weighted by the new capital imported from the North inv_{TT}.

The new productivities λ_{TT}^{new} and π_{TT}^{new} are modelled to replicate the learning-by-doing dynamics typical of new technological acquisitions. In other words, the Northern capital does not immediately become as productive as it is in the North when it is transferred to the South. Southern companies learn how to maximise its productive potential only after several periods. The equations of λ_{TT}^{new} and π_{TT}^{new} make sure that this effect is reproduced through a simple partial adjustment function:

$$\lambda_{TT}^{new} = \lambda_{TT_{-1}}^{new} + \mu_{TT}\left(\lambda_T^{new} - \lambda_{TT_{-1}}^{new}\right) \qquad (214)$$

$$\pi_{TT}^{new} = \pi_{TT_{-1}}^{new} + \mu_{TT}\left(\pi_T^{new} - \pi_{TT_{-1}}^{new}\right) \qquad (215)$$

This adjustment mechanism is governed by the exogenous parameter μ_{TT}, which determines the speed at which the productivity levels associated to the Northern capital (λ_T^{new} and π_T^{new}) are fully exploited by Southern companies. The value of μ_{TT} is chosen to simulate a reasonably fast integration of the new technology.

An important clarification needs to be made regarding import productivity. The traded sector has three non-capital productive inputs: labour, resources and imports (Section 4, Subsection 4.1). Each input has an associated productivity embedded in capital. As can be noted above, import productivity has been excluded from the technology transfer. This exclusion is justified by the fact that Northern imports are produced in the South. Therefore, it does not make sense to change the import consumption of the Southern traded sector in accordance with the import requirements of the Northern traded sector, because it would mean that the South would change its import requirements to goods that are actually produced in the South itself.

This issue complicates the overall discussion around technology transfer as the high level of resource productivity in the global North might be partially attributed to offshoring. Though it is indisputable that the developed world is more resource efficient even once we take into account imported goods, the possibility of fully transferring its resource productivity gains to the developing world remains unclear. However, in this model we shy away from this complicating issue and assume that the implementation of new technological capital from the North only affects labour and resource productivities.

9 Conclusion

This working paper has thoroughly described PADME, a novel 2-region SFC model developed to investigate the issue of post-growth in an international context. We have highlighted some of its original features such as the sectoral structure, cost-induced technological change and its novel investment function. These, among many others, have been introduced to better investigate important aspects of a post-growth transition. In particular, the PADME model is able to simulate a cap-and-trade system imposed on domestic and imported resources in one region (the North), which is a promising policy to start a post-growth transition. Moreover, the international side of the model allows us to explore cooperative policies between the North and the South. Again, important characteristics introduced in the model such as technology embedded in capital and a detailed financial system are fundamental to simulate the financial and technology transfer that have been described in the previous section. The purpose of this working paper was to cover in detail the structure of PADME so that future works based on this model will not require a thorough description of it. The interested reader can access this work to have an in-depth understanding of the functioning of the model. Future simulations include a scenario analysis of the cap in the closed-economy PADME, a scenario analysis of the introduction of the cap in the North while the South keeps developing (2-region PADME), the study of a cooperative post-growth transition where the North transfers financial and technological resources to the South.

Bibliography

Abel, A.B. and Bernanke, B. (2001), *Macroeconomics*, Fourth., Addison-Wesley, Boston.

Acemoglu, D. (2002), "Directed Technical Change", *The Review of Economic Studies*, Oxford Academic, Vol. 69 No. 4, pp. 781–809, doi: 10.1111/1467-937X.00226.

Agarwal, S., Chomsisengphet, S., Yildirim, Y. and Zhang, J. (2021), "Interest Rate Pass-Through and Consumption Response: The Deposit Channel", *The Review of Economics and Statistics*, MIT Press, Vol. 103 No. 5, pp. 922–938, doi: 10.1162/REST_A_00941.

Agarwal, S., Qian, W. and Tan, R. (2020), *Household Finance: A Functional Approach*, *Household Finance: A Functional Approach*, Springer , Singapore, doi: 10.1007/978-981-15-5526-8/COVER.

Aghion, P., Hepburn, C., Teytelboym, A. and Zenghelis, D. (2019), "Path dependence, innovation and the economics of climate change", in Fouquet, R. (Ed.), *Handbook on Green Growth*, Edward Elgar Publishing Ltd., pp. 67–83, doi: 10.4337/9781788110686.00011.

Banque de France (2024) Banque de France Statistics. https://www.banque-france.fr/en/publications-and-statistics/statistics

Beck, T., Demirgüç-Kunt, A. and Maksimovic, V. (2008), "Financing patterns around the world: Are small firms different?", *Journal of Financial Economics*, North-Holland, Vol. 89 No. 3, pp. 467–487, doi: 10.1016/J.JFINECO.2007.10.005.

Bernanke, B. (2015) "The Taylore Rule: A Benchmark For Monetary Policy?", Economic Studies, The Hutchins Center on Fiscal and Monetary Policy, Brookings.

BIS (2019) "Minimum capital requirements for market risk", Basel Committee on Banking Supervision, Bank for International Settlements.

Bond, S., Klemm, A., Newton-Smith, R., Syed, M., Vlieghe, G., Bakhshi, H., Bean, C., *et al.* (2004), "The roles of expected profitability, Tobin's Q and cash flow in econometric models of company investment We thank Nick Bloom and Jason Cummins for many helpful discussions, and participants at the Bank of England seminars for helpful comments, particularly", *Institute for Fiscal Studies, IFS Working Papers, W04/12*.

Bouis, R. (2019) "Banks' Holdings of Government Securities and Credit to the Private Sector in Emerging Market and Developing Economies", IMF Working Papers, WP/19/224.

Brochier, L. and Silva, A.C.M.E. (2019), "A supermultiplier Stock-Flow Consistent model: the 'return' of the paradoxes of thrift and costs in the long run?", *Cambridge Journal of Economics*, Oxford Academic, Vol. 43 No. 2, pp. 413–442, doi: 10.1093/CJE/BEY008.

Buch, C.M., Bussierè, M., Goldberg, L. and Hills, R. (2019), "The international transmission of monetary policy", *Journal of International Money and Finance*, Pergamon, Vol. 91, pp. 29–48, doi: 10.1016/J.JIMONFIN.2018.08.005.

Carruth, A., Dickerson, A. and Henley, A. (2000), "Econometric Modelling of UK Aggregate Investment: The Role of Profits and Uncertainty", *The Manchester School*, John Wiley & Sons, Ltd, Vol. 68 No. 3, pp. 276–300, doi: 10.1111/1467-9957.00194.

Castro, V. (2011), "Can central banks' monetary policy be described by a linear (augmented) Taylor rule or by a nonlinear rule?", *Journal of Financial Stability*, Elsevier, Vol. 7 No. 4, pp. 228–246, doi: 10.1016/J.JFS.2010.06.002.

Chirinko, R.S. (1993), "Business Fixed Investment Spending: Modeling Strategies, Empirical Results, and Policy Implications", *Journal of Economic Literature*, American Economic Association, Vol. 31 No. 4, pp. 1875–1911.

Corlet Walker, C., Druckman, A. and Jackson, T. (2021), "Welfare systems without economic growth: A review of the challenges and next steps for the field", *Ecological Economics*, Elsevier, Vol. 186, p. 107066, doi: 10.1016/J.ECOLECON.2021.107066.

Cosme, I., Santos, R. and O'Neill, D.W. (2017), "Assessing the degrowth discourse: A review and analysis of academic degrowth policy proposals", *Journal of Cleaner Production*, Elsevier, Vol. 149, pp. 321–334, doi: 10.1016/J.JCLEPRO.2017.02.016.

Cummins, J.G., Hassett, K.A. and Oliner, S.D. (2006), "Investment Behavior, Observable Expectations, and Internal Funds", *American Economic Review*, Vol. 96 No. 3, pp. 796–810, doi: 10.1257/AER.96.3.796.

Dafermos, Y. (2023), *Towards a Climate Just Financial System*.

Dafermos, Y., Nikolaidi, M. and Galanis, G. (2017), "A stock-flow-fund ecological macroeconomic model", *Ecological Economics*, Elsevier B.V., Vol. 131, pp. 191–207, doi: 10.1016/j.ecolecon.2016.08.013.

Daly, H. and Farley, J. (2011), *Ecological Economics: Principles and Applications*, Island Press.

Dunz, N., Naqvi, A. and Monasterolo, I. (2021), "Climate sentiments, transition risk, and financial stability in a stock-flow consistent model", *Journal of Financial Stability*, Elsevier, Vol. 54, p. 100872, doi: 10.1016/J.JFS.2021.100872.

ECB (2024) Banks Lending Margins Statistics, European Central Bank Data Portal. Data - Banks lending margins - Bank interest rates - ECB Statistical Data Warehouse (europa.eu)

ECB (2024b) Bank Interest rates Statistics, European Central Bank Data Portal. Deposits | ECB Data Portal (europa.eu)

Enache, C. (2022) Corporate Tax Rates around the World, Tax Foundation. Corporate Tax Rates by Country | Corporate Tax Trends | Tax Foundation

Fisher, J.D., Johnson, D.S., Smeeding, T.M. and Thompson, J.P. (2020), "Estimating the marginal propensity to consume using the distributions of income, consumption, and wealth", *Journal of Macroeconomics*, North-Holland, Vol. 65, p. 103218, doi: 10.1016/J.JMACRO.2020.103218.

Fontana, G. and Setterfield, M. (2009), "A Simple (and Teachable) Macroeconomic Model with Endogenous Money", *Macroeconomic Theory and Macroeconomic Pedagogy*, Palgrave Macmillan, London, pp. 144–168, doi: 10.1007/978-0-230-29166-9_9.

Gennaioli, N., Ma, Y. and Shleifer, A. (2016), "Expectations and investment", *NBER Macroeconomics Annual*, University of Chicago Press, Vol. 30 No. 1, pp. 379–431, doi: 10.1086/685965/ASSET/IMAGES/LARGE/FG5.JPEG.

Gerstberger, C. and Yaneva, D. (2013) "Analysis of EU-27 household final consumption expenditure", Statistics in focus Eurostat, 2.

Glyn, A. (1997), "Does aggregate profitability really matter?", *Cambridge Journal of Economics*, Oxford Academic, Vol. 21 No. 5, pp. 593–619, doi: 10.1093/OXFORDJOURNALS.CJE.A013688.

Godley, W. and Lavoie, M. (2007), *Monetary Economics: An Integrated Approach to Credit, Money, Income, Production and Wealth*, First., Springer.

Gräbner-Radkowitsch, C. and Strunk, B. (2023), "Degrowth and the Global South: The twin problem of global dependencies", *Ecological Economics*, Elsevier, Vol. 213, p. 107946, doi: 10.1016/J.ECOLECON.2023.107946.

Gray, S. (2011) "Central bank balances and reserve requirements", IMF Working Paper WP/11/36, 11–36.

Gregor, J., Melecký, A. and Melecký, M. (2021), "INTEREST RATE PASS-THROUGH: A META-ANALYSIS OF THE LITERATURE", *Journal of Economic Surveys*, John Wiley & Sons, Ltd, Vol. 35 No. 1, pp. 141–191, doi: 10.1111/JOES.12393.

Gropp, R., Kok, C. and Lichtenberger, J.D. (2014), "The Dynamics of Bank Spreads and Financial Structure", *The Quarterly Journal of Finance*, World Scientific Publishing Company and Midwest Finance Association , Vol. 4 No. 4, doi: 10.1142/S2010139214500141.

Hannsgen, G. (2007), "Chapter 13: The Transmission Mechanism of Monetary Policy: A Critical Review", *A Handbook of Alternative Monetary Economics*, Edward Elgar Publishing, Cheltenham, UK, doi: 10.4337/9781847202802.00018.

Hardt, L., Barrett, J., Taylor, P.G. and Foxon, T.J. (2021), "What structural change is needed for a post-growth economy: A framework of analysis and empirical evidence", *Ecological Economics*, Elsevier, Vol. 179, p. 106845, doi: 10.1016/J.ECOLECON.2020.106845.

Hartwig, J. (2011), "TESTING THE BAUMOL–NORDHAUS MODEL WITH EU KLEMS DATA", *Review of Income and Wealth*, John Wiley & Sons, Ltd, Vol. 57 No. 3, pp. 471–489, doi: 10.1111/J.1475-4991.2010.00409.X.

Hein, E. (2018), "Autonomous government expenditure growth, deficits, debt, and distribution in a neo-Kaleckian growth model", *Journal of Post Keynesian Economics*, Routledge, Vol. 41 No. 2, pp. 316–338, doi: 10.1080/01603477.2017.1422389.

Hickel, J., Brockway, P., Kallis, G., Keyßer, L., Lenzen, M., Slameršak, A., Steinberger, J., *et al.* (2021), "Urgent need for post-growth climate mitigation scenarios", *Nature Energy*, Nature Research, Vol. 6 No. 8, pp. 766–768, doi: 10.1038/S41560-021-00884-9.

Hickel, J., Kallis, G., Jackson, T., O'Neill, D.W., Schor, J.B., Steinberger, J.K., Victor, P.A.A., *et al.* (2022), "Degrowth can work — here's how science can help", *Nature 2022 612:7940*, Nature Publishing Group, Vol. 612 No. 7940, pp. 400–403, doi: 10.1038/d41586-022-04412-x.

Horváth, R. and Podpiera, A. (2012), "Heterogeneity in bank pricing policies: The Czech evidence", *Economic Systems*, North-Holland, Vol. 36 No. 1, pp. 87–108, doi: 10.1016/J.ECOSYS.2011.03.002.

ILO (2020) International Labour Organisation – processed by Our World in Data. "10.4.1 - Labour share of GDP (%) - SL_EMP_GTOTL" [dataset]. International Labour Organisation [original data]. Labor share of gross domestic product (GDP), 2020 (ourworldindata.org)

IMF (2022) International Monetary Fund – processed by the World Bank. "Bank Liquid Reserves to Banks Assets Ratio (%)" International Monetary Fund, International Financial Statistics and data files. Bank liquid reserves to bank assets ratio (%) - United States, Japan, Canada, Brazil, Denmark, Russian Federation, Korea, Rep. | Data (worldbank.org)

IRP (2017) "Assessing global resource use: A systems approach to resource efficiency and pollution reduction", Bringezu, S., Ramaswami, A., Schandl, H., O'Brien, M., Pelton, R., Acquatella, J., Ayuk, E., Chiu, A., Flanegin, R., Fry, J., Giljum, S., Hashimoto, S., Hellweg, S., Hosking, K., Hu, Y., Lenzen, M., Lieber, M., Lutter, S., Miatto, A., Singh Nagpure, A., Obersteiner, M., van Oers, L., Pfister, S., Pichler, P., Russell, A., Spini, L., Tanikawa, H., van der Voet, E., Weisz, H., West, J., Wiijkman, A., Zhu, B., Zivy, R. A Report of the International Resource Panel. United Nations Environment Programme.

Jackson, A. and Jackson, T. (2021), "Modelling energy transition risk: The impact of declining energy return on investment (EROI)", *Ecological Economics*, Elsevier B.V., Vol. 185, doi: 10.1016/j.ecolecon.2021.107023.

Jackson, T. (2009), *Prosperity without Growth: Economics for a Finite Planet*, *Prosperity without Growth: Economics for a Finite Planet*, Routledge, doi: 10.4324/9781849774338.

Jackson, T. and Victor, P.A. (2015), "Does credit create a 'growth imperative'? A quasi-stationary economy with interest-bearing debt", *Ecological Economics*, Elsevier, Vol. 120, pp. 32–48, doi: 10.1016/J.ECOLECON.2015.09.009.

Jackson, T. and Victor, P.A. (2020), "The Transition to a Sustainable Prosperity-A Stock-Flow-Consistent Ecological Macroeconomic Model for Canada", *Ecological Economics*, Elsevier, Vol. 177, p. 106787, doi: 10.1016/J.ECOLECON.2020.106787.

Jackson, Tim. (2017), "Prosperity without growth : foundations for the economy of tomorrow", Routledge, Taylor & Francis Group, p. 310.

Kalecki, M. (1965), *Theory of Economic Dynamics*, Second., Allen and Unwin.

Koepke, R. (2019), "WHAT DRIVES CAPITAL FLOWS TO EMERGING MARKETS? A SURVEY OF THE EMPIRICAL LITERATURE", *Journal of Economic Surveys*, John Wiley & Sons, Ltd, Vol. 33 No. 2, pp. 516–540, doi: 10.1111/JOES.12273.

Lavoie, M. (2022), "Post-Keynesian economics: New foundations", *Post-Keynesian Economics: New Foundations*, Edward Elgar Publishing Ltd., pp. 1–744, doi: 10.4337/9781839109621.

Leoni, D., Jackson, A. and Jackson, T. (2023), “Post Growth and the North-South Divide: a post-Keynesian stock-flow consistent analysis”, *CUSP Working Paper*.

Mano, R.C. and Castillo, M. (2015), *The Level of Productivity in Traded and Non-Traded Sectors for a Large Panel of Countries*, No. 2015/048.

Martin, C. and Milas, C. (2004), “Modelling Monetary Policy: Inflation Targeting in Practice”, *Economica*, [London School of Economics, Wiley, London School of Economics and Political Science, Suntory and Toyota International Centres for Economics and Related Disciplines], Vol. 71 No. 282, pp. 209–221.

Menon, J. (1995), “EXCHANGE RATE PASS-THROUGH”, *Journal of Economic Surveys*, Vol. 9 No. 2, pp. 197–231, doi: https://doi.org/10.1111/j.1467-6419.1995.tb00114.x.

Nadiri, M.I. and Prucha, I.R. (1996), “ESTIMATION OF THE DEPRECIATION RATE OF PHYSICAL AND R&D CAPITAL IN THE U.S. TOTAL MANUFACTURING SECTOR”, *Economic Inquiry*, John Wiley & Sons, Ltd, Vol. 34 No. 1, pp. 43–56, doi: 10.1111/J.1465-7295.1996.TB01363.X.

Naqvi, A. and Stockhammer, E. (2018), “Directed Technological Change in a Post-Keynesian Ecological Macromodel”, *Ecological Economics*, Elsevier B.V., Vol. 154, pp. 168–188, doi: 10.1016/J.ECOLECON.2018.07.008.

Nordhaus, W.D. (2008), “Baumol’s diseases: A macroeconomic perspective”, *B.E. Journal of Macroeconomics*, Walter de Gruyter GmbH, Vol. 8 No. 1, doi: 10.2202/1935-1690.1382/MACHINEREADABLECITATION/RIS.

OECD (2023a) *SUT indicators*, OECD Statistics. SUT Indicators : Share of imported products in final consumption of households at basic prices (oecd.org)

OECD (2023b) The OECD Tax Database. OECD Tax Database - OECD

OECD (2023c) Employment — Hours worked, OECD data. Employment - Hours worked - OECD Data

OECD (2024) Benefits in unemployment, share of previous income, OECD data. Benefits and wages - Benefits in unemployment, share of previous income - OECD Data

Oliveira Martins, J., S. Scarpetta and D. Pilat (1996), "Mark-Up Ratios in Manufacturing Industries: Estimates for 14 OECD Countries", OECD Economics Department Working Papers, 162, OECD Publishing, Paris.

Özyurt, S. (2016) “Has the exchange rate pass through recently declined in the euro area?”, Working paper series No 1955, European Central Bank.

Reinhart, C.M. and Rogoff, K.S. (2010), “Growth in a Time of Debt”, *American Economic Review*, Vol. 100 No. 2, pp. 573–578, doi: 10.1257/AER.100.2.573.

Rosenbaum, E. (2015), “Zero growth and structural change in a post Keynesian growth model”, *Journal of Post Keynesian Economics*, Routledge, Vol. 37 No. 4, pp. 623–647, doi: 10.1080/01603477.2015.1050334.

Ross, J. (2022) Interest rate hikes vs inflation: How are different countries doing it?, World Economic Forum. Interest rates vs inflation: Country by country approach | World Economic Forum (weforum.org)

Sharpe, S.A. and Suarez, G. (2015) “Why isn't investment more sensitive to interest rates: evidence from surveys”, Finance and Economics Discussion Series, 002, Federal Reserve Board, Washington, D.C.

Slameršak, A., Kallis, G., O’Neill, D.W. and Hickel, J. (2024), “Post-growth: A viable path to limiting global warming to 1.5°C”, *One Earth*, Cell Press, Vol. 7 No. 1, pp. 44–58, doi: 10.1016/J.ONEEAR.2023.11.004/ASSET/C4406FA7-564B-4151-966F-1154DAEB0C58/MAIN.ASSETS/GR5.JPG.

Stavins, R.N. (2008), “A Meaningful U.S. Cap-and-Trade System to Address Climate Change”, *Harvard Environmental Law Review*, Vol. 32.

Sue Wing, I. (2006), “Representing induced technological change in models for climate policy analysis”, *Energy Economics*, North-Holland, Vol. 28 No. 5–6, pp. 539–562, doi: 10.1016/J.ENECO.2006.05.009.

Sue Wing, I. (2008), “Explaining the declining energy intensity of the U.S. economy”, *Resource and Energy Economics*, North-Holland, Vol. 30 No. 1, pp. 21–49, doi: 10.1016/J.RESENEECO.2007.03.001.

Thum, A. E. and Canton, E. (2015) “Estimation of service sector mark-ups determined by structural reform indicators”, No. 547, Directorate General Economic and Financial Affairs (DG ECFIN), European Commission.

UIS (2023) UNESCO Institute for Statistics (UIS) – processed by the World Bank. “Research and Development expenditure (% of GDP)” UNESCO Institute for Statistics, UIS.Stat Bulk Data.

Victor, P.A. and Jackson, T. (2020), “A research agenda for ecological macroeconomics”, in Costanza, R., Erickson, J.D., Farley, J. and

Kubiszewski, I. (Eds.), *Sustainable Wellbeing Futures: A Research and Action Agenda for Ecological Economics*, Edward Elgar Publishing Ltd., pp. 357–372, doi: 10.4337/9781789900958.00032.

Appendix

A.1 Notation used in the model

Variables represented with Latin letters

Nominal	Real	
$ASSETS$		Total assets held by the banking sector
B		Bonds
CAB		Current account balance
CJ		Climate Justice bonds
$CONS$	$cons$	Consumption
D		Deposits
$Debt$		Public Debt-to-GDP ratio
E		Employment rate
F		Profits
FE		Full employment
G	g	Goverment spending
HH		Centrall banks's reserves
IC	ic	Intermediate goods
INV	inv	Investment
IT		International transfer
K	k	Capital
KAB		Financial account balance
L		Loans
M	m	Imports
N		Number of employed workers
OF		Banking sector's equity/own funds.
Q		Population
R	r	Resources
$R\&D_{ratio}$		R&D expenditure-to-GDP ratio
S	s	Sales

Variables represented with Latin letters

Sub		Government subsidies
T		Tax income
TT		Technology transfer
V		Wealth
W	w	Wages
X	x	Exports
Y	y	Gross value added
YD		Nominal disposable income
i		Interest rate
p		Prices
t		Tax rate
wh		Working hours

Variables represented with Greek letters and other symbols

Φ_R	Resource sector's unitary costs.
Ψ_R	Partial adjustment parameter.
α_0	Partial adjustment parameter
β_0	Partial adjustment parameter
κ_0	Parameter that weights the importance of past real sales for the determination of target sales.
κ_1	Parameter that weights the importance of past real profits for the determination of target sales.
λ_0	Parameter translating investment in labour-saving technology in a growth rate for labour productivity.
ν_0	Parameter determining the intensity of the impact that a change in interest rates has on capitalists' consumption.
ξ_0	Parameter translating investment in intermediate good-saving technology in a growth rate for intermediate good productivity.
π_0	Parameter translating investment in resource-saving technology in a growth rate for resource productivity.

Variables represented with Greek letters and other symbols

ς_0	Exogenous steady state growth rate for government spending.
ς_1	Partial adjustment parameter
ℓ	Parameter that determines the allocation of public subsidies to the different sectors.
Θ	Share of government spending devoted to R&D activities
Π	Parameter that determines the share of tariff income allocated to the international financial transfer.
$\mho$	Research and development income
α	Coefficient determining the share of consumption devoted to non-traded goods.
β	Coefficient determining the share of consumption devoted to non-traded goods.
δ	Capital depreciation rate.
ε	Exchange rate
η	Mark-up
θ	Coefficient determining the share of disposable income devoted to consumption.
ι	Parameter that regulates the speed of change in the policy rate by the central bank to a change in inflation.
κ	Output-capital ratio
λ	Labour productivity.
μ	Partial adjustment parameter.
ξ	Intermediate goods productivity.
π	Resource productivity.
ρ	Parameter determining the amount of reserves held by banks as a share of deposits.
ς	Government spending growth rate
σ	Parameter that weights the importance of the exchange rate and domestic and foreign prices for the determination of the export price.
τ	Parameter determining the amount of equity held by banks as a share of total loans.
υ	Parameter determining the share of tariff income allocated to the technology transfer.

Variables represented with Greek letters and other symbols

φ	Coefficient determining the public unemployment benefit as a share of average wages.
ω	Parameter that weights the importance of unemployment and labour productivity for the determination of the target real wage.
ϵ	Parameter determining the level of substitutability between different productive inputs.
ϑ	Share of investment financed by retained profits.
ϕ	Parameter determining the amount of international bonds purchased by by banks as a share of their total assets.
ϱ	Shares of R&D spending allocated to different technologies.
ϖ	Labour share

Superscripts and subscripts

av	Average
B	Banking sector
C	Capital income
CB	Central Bank
CJ	Climate Justice
D	Non-traded sector
D	Subscript: Deposits. Superscript: Demand for an asset.
ds	Domestic sales
F	Firms
G	Government sector
gt	Growth rate
H	Household sector
hh	Reserves
ic	Intermediate goods
inv	Investable
K	Capital

Superscripts and subscripts

m	Imports
N	North region
N	Labour
new	New
R	Resource sector
R	Resources
$R\&D$	Research and Development
S	South region
S	Supply of an asset
T	Traded sector
tot	Total
TT	Technology transfer
U	Undistributed
up	Upper threshold
w	Wages
ws	Welfare state
x	Exports
ϖ	Labour share

A.2 Model calibration

The structure of this section follows the structure of the description of the PADME model. Hence, the values of the parameters of the household sector are introduced first (**Error! Reference source not found.**), then those of the government sector (Table A. 1), firms sector (Table A.2), banking sector and central bank (Table A. 4) and lastly of the R&D module (Table A.4) and labour market (Table A.5).

Table A. 1 Household Sector

Exogenous parameters			
Symbol	**Description**	**Value**	**Justification/source.**
α_0	Adjustment parameter that determines the speed at which nominal consumption of the non-traded good moves towards its real target value.	0.2	All the adjustment parameters have been calibrated following the SFC literature, which generally attributes them values between 0.1 and 0.2 (Godley and Lavoie, 2007; Dafermos et al., 2017).
β_0	Adjustment parameter that determines the speed at which nominal consumption of the imported good moves towards its real target value.	0.2	Selected from a reasonable range of values generally attributed to adjustment parameters (see α_0).
$\bar{\alpha}_H$	Households' real target threshold for consumption of the non-traded good.	0.575	Based on Eurostat data, households' share of consumption of services is approximately half of total consumption (Gerstberger and Yaneva, 2013).
$\bar{\beta}_H$	Households' real target consumption for the imported good.	0.125	Household final consumption of imported good is around 15% of real consumption according to OECD data (OECD, 2023a).

θ_0	Propensity to consume out of wage income.	1	Theoretical value based on post-Keynesian (typically Kaleckian) models. Also, very close to empirical estimates of the average propensity to consume of low-income households (Fisher *et al.*, 2020).
θ_2	Propensity to consume out of wealth	0.05	In most recent SFC models, the value of this parameter range from 0.03 (Brochier and Silva, 2019) to 0.1(Dunz *et al.*, 2021). This value has been chosen as it is the same in Jackson and Jackson (2021) and Naqvi and Stockhammer (2018).
	Endogenous parameters		
θ_1	Propensity to consume out of capital income.	0.5	Based on empirical estimations of high-income households' propensity to consume in Fisher et al. (2020). The simplifying assumption here is that the capitalist class constitutes the richest part of the population and thus their propensity to consume is lower than that of other households.
α_H	Share of household nominal consumption devoted to the non-traded good.	0.62	Selected to obtain a real consumption of the non-traded good around 50% of total consumption (Gerstberger and Yaneva, 2013).
β_H	Share of household nominal consumption devoted to the non-traded good.	0.65	Selected to obtain a real consumption of the imported good around 15% of total consumption. Based on OECD data (OECD, 2023a).

ν_0	Sensitivity of the propensity to consume of capitalists to the interest rate on deposits.	1.5	Selected from a reasonable range of values. By reasonable I refer to a value that allows for a moderate reaction of consumption to interest rate changes as highlighted in the empirical literature (Agarwal et al., 2021).

Table A. 1 Government Sector

Exogenous parameters			
t_c	Tax rate on capital income.	0.2	Based approximately on an average of the countries included in the OECD tax database (OECD, 2023b).
t_f	Tax rate on firms' gross profits.	0.2	Based approximately on an average of the countries included in the 2021 report on corporate tax rate of the Tax Foundation (Enache, 2022).
t_m	Tariff rate on imports.	1	Given the specification of equation 35, 1 means that the actual tariff rate is zero in the steady state.
t_w	Tax rate on wage income.	0.3	Based approximately on an average of the countries in the OECD tax database (OECD, 2023b).
$\bar{\alpha}_G$	Government real target consumption for the non-traded good.	0.575	Selected to mirror households' consumption parameters.
$\bar{\beta}_G$	Government real target consumption for the imported good.	0.125	Selected to mirror households' consumption parameters.
φ	Share of average nominal wage paid by the government as unemployment insurance.	0.6	Based on an average of OECD countries (OECD, 2024).

$\overline{Debt}$	Target threshold for the public debt-to-GDP ratio after which the government starts to cut down its expenditure.	0.8	Regardless of the controversy around the empirical evidence, the work of (Reinhart and Rogoff, 2010) has popularised the idea that 90% is generally considered a sensible threshold after which public debt becomes harmful for the economy. Hence, the assumption is that the government tries to reduce expenditure when the ratio gets close to that number.
ς_0	Growth rate of government expenditure when the public debt-to-GDP ratio is within sustainable limits (which are defined by an exogenous threshold).	0.01	Chosen to match the growth rate of labour productivity in the steady state.
ς_1	Adjustment parameter that determines the speed at which government cuts its expenditure to reach financial sustainability.	0.05	Selected from a reasonable range of values to guarantee the stability of the model.
	Endogenous parameters		
α_G	Share of government nominal consumption devoted to the non-traded good.	0.62	Selected to mirror the parameters in the household sector.
β_G	Share of government consumption devoted to the traded good.	0.65	Selected to mirror the parameters in the household sector.

Table A.2 Firms Sector

	Exogenous parameters		
Ψ_R	Adjustment parameter for the unit costs of the resource module.	0.2	Selected from a reasonable range of values generally attributed to adjustment parameters (see α_0).

η_D	Mark-up over unit costs of the non-traded sector.	0.35	The value of the mark-ups are selected to obtain a realistic distribution between capital and labour, i.e., the labour share is between 55% and 60% of GDP (ILO, 2020). Moreover, they ensure that the profit rates of the different sectors are approximately the same. Empirical evidence cannot be used here as estimates of mark-ups do not match the formulation in this model (Oliveira Martins et al., 1996; Thum and Canton, 2015).
η_R	Mark-up over unit costs of the resource module.	0.3	
η_T	Mark-up over unit costs of the traded sector.	0.45	
σ_1	Sensitivity of the export price to the exchange rate and the other country domestic price.	0.5	Empirical evidence on exchange rate pass-throughs shows that movements in exchange rates are never fully reflected in import prices (Menon, 1995; Özyurt, 2016). Thus, any pass-through is incomplete. Estimates vary widely both for countries, sectors and periods of time. The choice here is made to easily obtain identical, symmetrical economic regions. Hence, this value is primarily chosen in terms of theoretical convenience, but still accounts for a well-established fact in the literature.
ϵ_0	Sensitivity of the actual use of an input to changes in its own price.	0.1	Selected from a reasonable range of values. This value allows for a modest substitution effect as shown in Sue Wing (2008).
ϵ_1	Sensitivity of the actual use of an input to changes in other input prices.	0.05	Selected from a reasonable range of values. See ϵ_0.
δ	Depreciation rate of real capital.	0.06	Estimates vary between 4% and 10% (Dafermos *et al.*, 2017; Jackson and Victor, 2015; Nadiri and Prucha, 1996).

κ	Output-to-capital ratio for the firms sector.	0.6723	Selected from a reasonable range of values. This allows to obtain a stable steady state, though the capital-to-output ratio is slightly below the value suggested by the empirical evidence.
κ_0	Weight attached to real sales for determining desired sales of the firm sectors.	0.95	These two weights have been chosen so that the impact of interest rate increases on investment is relatively feeble (a 100 basis points increase in the policy rate leads to a decrease of aggregate investment growth rate by 0.45% in one period). This is in line with empirical evidence showing that changes in interest rates have mild impacts on real investment (Sharpe and Suarez, 2015).
κ_1	Weight attached to real profits for determining desired sales of the firm sectors.	0.2	
μ_D	Partial adjustment parameter for the investment function of the non-traded sector.	0.1	This value is in line with those traditionally used in SFC models (Godley and Lavoie (2007), Jackson and Jackson (2021)).
μ_T	Partial adjustment parameter for the investment function of the traded sector.	0.1	This value is in line with those traditionally used in SFC models (Godley and Lavoie (2007), Jackson and Jackson (2021)).
ϑ_T	Share of investment financed by own funds of the traded sector.	0.75	Empirical evidence shows that internal financing is extremely different from country to country (Beck *et al.*, 2008). This value is taken as an average of the different estimates found in Beck et al. (2008).
ϑ_D	Share of investment financed by own funds of the non-traded sector.	0.75	
	Endogenous parameters		
Φ_R	Unit costs of the resource module.	0.5	Initial value selected to produce a stable steady state.

Table A.3 Banking Sector and Central Bank

Exogenous parameters			
ρ	Parameter that determines the level of reserves of the banking sector as a share of deposits.	0.05	Before the widespread use of Quantitative Easing, the ratio of reserves over total assets was close to zero in many developed countries (IMF, 2022). Developing countries have generally had higher reserve-to-assets ratio given the high reserve requirements imposed there (Gray, 2011). The value is a rough average of the pre-QE ratios in developed and developing countries.
τ	Parameter that determines the level of own fund of the banking sector as a share of loans lent to the firms sector.	0.08	The minimum capital ratio as set out in the guidelines of Basel 3 (BIS, 2019).
ϕ_0	Share of banks' asset invested in foreign bonds.	0.15	Roughly based on an average of the estimates presented in Bouis (2019).
η_0	Banks' mark-up added to the policy rate to determine the interest rate on loans.	0.03	Roughly based on averages estimated by the Banque de France (2024) and ECB (2024a).
η_1	Lower bound for a 1-period change in the mark-up on loans.	-0.01	Selected from a reasonable range of values. The rationale here is to have parameter values that are sufficiently stable. Otherwise, the model could have unrealistic fluctuations and might crash.
η_2	Parameter that regulates the sensitivity of the mark-up on loans to changes in the credit risk of firms.	0.0005	
η_3	Upper bound for a 1-period change in the mark-up on loans.	0.02	

η_d	Mark-up over the interest rate on reserves that allows to determine the interest rate on deposits.	0.005	Roughly based on ECB (2024b) data.
η_g	Mark-up over the interest rate on reserves that allows to determine the interest rate on bonds.	0.02	Selected from a reasonable range of values.
ι_0	Sensitivity of the central bank's policy rate to a decrease of the domestic inflation rate above its target level.	0.6	Traditionally, the theoretical value has been 0.5 (Bernanke, 2015). Empirical evidence seems to suggest a higher coefficient (Castro, 2011), but in the after-pandemic environment interest rate have reacted much more sluggishly (Ross, 2022). Therefore, 0.6 seems sensible as an average of old and new findings.
ι_1	Sensitivity of the central bank's policy rate to a decrease of the domestic inflation rate below its target level.	0.3	Empirical evidence shows that central banks react less quickly when inflation rate is below their target level (Martin and Milas, 2004; Castro, 2011). Thus, the choice of $\iota_1 < \iota_0$. 0.3 is also close to Martin and Milas' (2004) estimate.

Table A.4 R&D Module

	Exogenous parameters		
Θ_D	Share of profits of the non-traded sector allocated to R&D.	0.05	The values of these three parameters are chosen to obtain two empirically reasonable outcomes. Firstly, that total R&D expenditure-to-GDP ratio is approximately 2% (UIS, 2023). Moreover, that the share of R&D funded by the
Θ_G	Share of government spending allocated to R&D.	0.025	

Θ_T	Share of profits of the traded sector allocated to R&D.	0.05	government is around 35% of the total (Eurostat, 2024).
$\Psi_{R\&D}$	Parameter that regulates the speed with which the supply of labour for R&D activities increases.	0.2	Selected from a reasonable range of values. The rationale here is to have a value that allows the real output of R&D activities to grow at a sensible rate in the long run even if full employment is reached in the short run.
λ_0	Sensitivity of the labour productivity growth rate to changes in the level of investment in R&D.	0.1	Selected from a reasonable range of values. The value here is chosen so that higher labour productivity reacts in a realistic way to new investment in R&D.
ξ_0	Sensitivity of the intermediate good productivity growth rate to changes in the level of investment in R&D. The intermediate good here refers to the use of the imported good by the traded sector.	0.1	Selected from a reasonable range of values. The rationale is the same as above for labour productivity.
ξ_0^T	Sensitivity of the intermediate good productivity growth rate to changes in the level of investment in R&D. The intermediate good here refers to the use of the domestic traded good by the non-traded sector.	0.1	Selected from a reasonable range of values. The rationale is the same as above for labour productivity.
ξ_0^m	Sensitivity of the intermediate good productivity growth rate to changes in the level of investment in R&D. The intermediate good here refers to the use of the imported good by the non-traded sector.	0.1	Selected from a reasonable range of values. The rationale is the same as above for labour productivity.

π_0	Sensitivity of the resource productivity growth rate to changes in the level of investment in R&D.	0.1	Selected from a reasonable range of values. The rationale is the same as above for labour productivity.
ϱ_{00}^{D}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	3	Selected from a reasonable range of values. This makes the different productivities responsive to changes in inflation rates. Otherwise, the effect would be too small to significantly affect the model.
ϱ_{00}^{T}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	3	Selected from a reasonable range of values. See above.
ϱ_{01}^{D}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	1.5	Selected from a reasonable range of values. Again, this makes the different productivities responsive enough to changes in inflation rates
ϱ_{01}^{T}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{02}^{D}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{02}^{T}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	1.5	Selected from a reasonable range of values. See above.

ϱ_0^D	Share of non-traded sector R&D spending devoted to labour productivity.	0.9	Selected to allow for a 1% productivity growth rate of labour. Given that the growth rate of the model is 1%, this allows to obtain a stable employment rate in the steady state.
ϱ_0^T	Share of traded sector R&D spending devoted to labour productivity.	0.9	
ϱ_{10}^D	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{10}^T	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{11}^D	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	3	Selected from a reasonable range of values. The idea behind the values of all the parameters in the portfolio allocation equations is to provide a sufficiently responsive reaction of R&D activities to changes in input prices.
ϱ_{11}^T	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	3	Selected from a reasonable range of values. See above.
ϱ_{12}^D	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	1.5	Selected from a reasonable range of values. See above.

ϱ_{12}^{T}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{1}^{D}	Share of non-traded sector R&D spending devoted to import productivity.	0.05	Selected to allow for a 0% productivity growth rate of imported inputs. This simplifies a lot the possibility to reach a stable steady state.
ϱ_{1}^{T}	Share of traded sector R&D spending devoted to import productivity.	0.05	
ϱ_{20}^{D}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{20}^{T}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{21}^{D}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	1.5	Selected from a reasonable range of values. See above.
ϱ_{21}^{T}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	1.5	Selected from a reasonable range of values. See above.

ϱ_{22}^{D}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the non-traded sector.	3	Selected from a reasonable range of values. See above.
ϱ_{22}^{T}	Portfolio parameter that determines the sensitivity of R&D spending to the inflation rates of the productive inputs in the traded sector.	3	Selected from a reasonable range of values. See above.
ϱ_{2}^{D}	Share of non-traded sector R&D spending devoted to domestic traded good productivity.	0.05	Selected to allow for a 0% productivity growth rate of intermediate inputs. See above.
ϱ_{2}^{T}	Share of traded sector R&D spending devoted to resource productivity.	0.05	Selected to allow for a 0% productivity growth rate of resources. This is line with empirical evidence at the global level (IRP, 2017). There are clearly differences in resource efficiency growth rates between North and South, but this assumption allows us to obtain a stable steady state.
ϱ_{ic}^{GD}	Share of government R&D spending devoted to the productivity of intermediate goods in the non-traded sector.	0.05	Selected to allow for a 0% productivity growth rate of intermediate inputs. See above
ϱ_{ic}^{GT}	Share of government R&D spending devoted to import productivity of the traded sector.	0.05	Selected to allow for a 0% productivity growth rate of imported inputs. See above.
ϱ_{m}^{GD}	Share of government R&D spending devoted to import productivity of the non-traded sector.	0.05	

ϱ_n^{GD}	Share of government R&D spending devoted to labour productivity of the non-traded sector.	0.9	Selected to allow for a 1% growth rate of labour productivity.
ϱ_n^{GT}	Share of government R&D spending devoted to labour productivity of the traded sector.	0.9	
ϱ_r^{GT}	Share of government R&D spending devoted to resource productivity of the traded sector.	0.05	Selected to allow for a 0% productivity growth rate of resources.
$\lambda_{R\&D}^{gt}$	Productivity growth rate of R&D activities.	0.01	Selected to remain in line with the steady-state growth rate of the model.

Table A.5 Labour Market

Exogenous parameters			
ϖ_0	Parameter of the equation determining the real wage level.	-0.36	Selected to obtain an inflation rate around 2% in the steady state.
ϖ_1	Sensitivity of real wages to the level of labour productivity.	1	Selected to obtain a stable steady state where the model grows at 1%.
ϖ_2	Sensitivity of real wages to the level of employment.	0.75	Selected from a reasonable range of values.
ϖ_3	Partial adjustment parameter for the determination of nominal wages.	0.1	Selected from a reasonable range of values. A value within the 0.05-0.2 interval allows for a more stable model.
wh	Number of working hours per worker per year.	1680	Approximately the OECD average (OECD, 2023c).

E^{up}	The upper limit of the employment rate, after which new workers start to join the workforce.	0.96	Generally, unemployment rates around 4% are considered frictional.

Appendix B Matrices

This Appendix reports the balance sheet and transaction flow matrices for the PADME model. Their meaning and interpretation are described in Section 2, Subsection 2.3. We portray both matrices split by regions, with the matrix for each region occupying one page. Furthermore, we represent in bold the variables that are added to simulate the technology transfer introduced in Section 8. It is important to bear in mind that the variables in bold are equal to zero apart for when the technology transfer is simulated.

B.1 Transaction flow matrix

In the pages below, we report the transaction-flow matrix. The positive and negative signs represent the source and use of funds respectively. For instance, consumption is a use of funds for the household sector and a source of funds for the firm sectors.

The matrix of each region is split into two sections. Each of these sections is in a separate page for the sake of readability. The first part concerns the movements of income and expenditure flows, while the second part (the one starting with the title '*changes in stock*') illustrate the changes in financial positions. The connection between the two parts is straightforward. All the income that is not spent by a sector (first part) must result in a change in that sector's financial position in the form of an increase in its assets (second part). Conversely, a sector that spends more than it earns must borrow, thus its surplus decreases (or its deficit increases) vis a vis the rest of the economy. This change in assets is represented with the symbol Δ. Lastly, for the model to be stock-flow consistent, all rows and columns must sum to zero.

North

	Households (h)	Non-traded sector (d)		Resource sector (r)		Traded sector (t)		Government (g)	Banks (b)	CB (cb)	Exchange rate
Consumption (C)	-C	+C_d				+C_t					
Government Consumption (G)		+G_d				+G_t		-G			
Intermediate consumption (IC)		-IC				+IC					
Resource consumption (R)				+R		-R					
Imports North (M_N)/Exports South (X_S)	-MNh·xr	-M_{Nd}·xr				-M_{Nt}·xr		-M_{Ng}·xr			xr
Exports North (X_N)/Imports South (M_S)						+X_N					xr
Investment (INV)			-INV_d		-INV_r	+INV	-INV_t				
CJ Capital (CJK)						**+CJK**					
Wages (W)	+W	-W_d				-W_t					
Research and development (R&D)	+R&D	-R&D_d				-R&D_t		-R&D_g			
Unemployment insurance (Ψ)	+Ψ							-Ψ			
Retained profits (F_u)		-F_{ud}	+F_{ud}	-F_{ur}	+F_{ur}	-F_{ut}	+F_{ut}				
Distributed profits (F)	+F	-F_d		-F_r		-F_t					
Bank profits (F_b)	+F_b								-F_b		
Taxes (T)	-T_h	-T_d		-T_r		-T_t		+T			
Interests on deposits (i_D)	+i_D								-i_D		
Interests on North bonds (i_{BN})	+i_{BNh}							-i_{Bn}	+i_{BNb}	+i_{BNcb}	xr
Interests on South bonds (i_{BS})									+i_{BSb}·xr		xr
Interests on loans (i_L)		-i_{Ld}				-i_{Lt}			+i_L		
Interest on CJ bonds (i_{CJB})										**+i_{CJB}**	
Interests on CJ loans (i_{CJL})											
Central Bank profits (F_{cb})								+F_{cb}		-F_{cb}	

	Changes in Northern stocks							
	Households (h)	Non-traded sector (d)	Resource sector (r)	Traded sector (t)	Government (g)	Banks (b)	CB (cb)	Exchange rate (xr)
Changes in deposits (D)	$-\Delta D$					$+\Delta D$		
Changes in reserves (HH)						$-\Delta HH$	$+\Delta HH$	
Changes in North bonds (B_N)					$+\Delta B_N$	$-\Delta B_{Nb}$	$-\Delta B_{Ncb}$	xr
Changes in South bonds (B_S)						$-\Delta B_{Sb} \cdot xr$		xr
Changes in CJ bonds (CJB)							**$-\Delta CJB$**	
Changes in CJ loans (CJL)								
Changes in own funds (OF)	$-\Delta OF$					$+\Delta OF$		
Changes in loans (L)		$+\Delta L_d$		$+\Delta L_t$		$-\Delta L$		
Σ	0	0	0	0	0	0	0	

South

	Exchange rate	Households (h)	Non-traded sector (d)		Resource sector (r)		Traded sector (t)		Government (g)	Banks (b)	CB (cb)	Σ
Consumption (C)		-C	$+C_d$				$+C_t$					0
Government Consumption (G)			$+G_d$				$+G_t$		-G			0
Intermediate consumption (IC)			-IC				+IC					0
Resource consumption (R)					+R		-R					0
Imports North (M_N)/Exports South (X_S)	xr						X_S					0
Exports North (X_N)/Imports South (M_S)	xr	$-M_{Sh}\cdot xr$	$-M_{Sd}\cdot xr$				$-M_{St}\cdot xr$		$-M_{Sg}\cdot xr$			0
Investment (INV)				$-INV_d$		$-INV_r$	+INV	$-INV_t$				0
CJ Capital (CJK)								**-CJK**				**0**
Wages (W)		+W	$-W_d$				$-W_t$					0
Research and development (R&D)		+R&D	$-R\&D_d$				$-R\&D_t$		$-R\&D_g$			0
Unemployment insurance (Ψ)		+Ψ							-Ψ			0
Retained profits (F_u)			$-F_{ud}$	$+F_{ud}$	$-F_{ur}$	$+F_{ur}$	$-F_{ut}$	$+F_{ut}$				0
Distributed profits (F)		+F	$-F_d$		$-F_r$		$-F_t$					0
Bank profits (F_b)		$+F_b$								$-F_b$		0
Taxes (T)		$-T_h$	$-T_d$		$-T_r$		$-T_t$		+T			0
Interests on deposits (i_D)		$+i_D$								$-i_D$		0
Interests on North bonds (i_{BN})	xr									$+i_{BNb}\cdot xr$		0
Interests on South bonds (i_{BS})	xr	$+i_{BSh}$							$-i_{BS}$	$+i_{BSb}$	$+i_{BScb}$	0
Interests on loans (i_L)			$-i_{Ld}$				$-i_{Lt}$			$+i_L$		0
Interest on CJ bonds (i_{CJB})											**$-i_{CJB}$**	0
Interests on CJ loans (i_{CJL})							**$-i_{CJL}$**				**$+i_{CJL}$**	0
Central Bank profits (F_{cb})									$+F_{cb}$		$-F_{cb}$	0

Changes in Southern stocks

	Exchange rate	Households (h)	Non-traded sector (d)	Resource sector (r)	Traded sector (t)	Government (g)	Banks (b)	CB (cb)	Σ
Changes in deposit (D)		$-\Delta D$					$+\Delta D$		0
Changes in reserve (HH)							$-\Delta HH$	$+\Delta HH$	0
Changes in North bonds (B_N)	xr						$-\Delta B_{Nb} \cdot xr$		0
Changes in South bonds (B_S)	xr					$+\Delta B_S$	$-\Delta B_{Sb}$	$-\Delta B_{Scb}$	0
Changes in CJ bonds (CJB)								**$+\Delta CJB$**	0
Changes in CJ loans (CJL)					**$+\Delta CJL$**			**$-\Delta CJL$**	0
Changes in own funds (OF)		$-\Delta OF$					$+\Delta OF$		0
Changes in loans (L)			$+\Delta L_d$		$+\Delta L_t$		$-\Delta L$		0
Σ		0	0	0	0	0	0	0	0

B.2 Balance sheet matrix

Here, we show the balance sheet matrix for each region. The positive sign in a variable means that the variable is an asset, while the negative sign represents a liability. Each financial asset held by a sector is a corresponding liability for another sector. Hence, as long as only financial assets are concerned, all rows and columns of the matrix should sum to zero. However, real assets like capital do not have a corresponding liability, therefore a model in which the economy produces capital has a positive net worth equal to the value of the capital stock.

		South							
	Exchange rate (xr)	Household (h)	Traded (t)	Non-traded (d)	Resource (r)	Government (g)	Banking (b)	Central Bank (cb)	Σ
Reserves (HH)							+HH	-HH	0
Deposits (D)		+D					-D		0
Bonds North (B_N)	xr						$+B_{Nb}$		0
Bonds South (B_S)	xr					$-B_S$	$+B_{Sb}$	$+B_{Scb}$	0
Loans (L)			$-L_t$	$-L_d$			+L		0
CJ Bonds (CJB)								**-CJB**	0
CJ Loans (CJL)			**-CJL**					**+CJL**	0
Own Funds (OF)		+OF					-OF		0
Capital (K)			$+K_t$ **+** $\mathbf{K_{CJ}}$	$+K_d$	$+K_r$				$K_N + K_S$
Balance		$-V_h$	$-V_t$	$-V_d$	$-V_r$	$-V_g$	0	0	$-K_N - K_S$
Σ		0	0	0	0	0	0	0	0

	North							
	Household (h)	Traded (t)	Non-traded (d)	Resource (r)	Government (g)	Banking (b)	Central Bank (cb)	Exchange rate (xr)
Reserves (HH)						+HH	-HH	
Deposits (D)	+D					-D		
Bonds North (B_N)					$-B_N$	$+B_{Nb}$	$+B_{Ncb}$	Xr
Bonds South (B_S)						$+B_{Sb}$		Xr
Loans (L)		$-L_t$	$-L_d$			+L		
CJ Bonds (CJB)							**+CJB**	
CJ Loans (CJL)								
Own Funds (OF)	+OF					-OF		
Capital (K)		$+K_t$	$+K_d$	$+K_r$				
Balance	$-V_h$	$-V_t$	$-V_d$	$-V_r$	$-V_g$	0	0	
Σ	0	0	0	0	0	0	0	