CHARLES UNIVERSITY
FACULTY OF SOCIAL SCIENCES
Institute of Economic Studies

Multi-country ABM perspective on business cycles and deleveraging crises

Master's thesis

Author: Bc. Alexander Mačejovský

Study program: Economics and Finance

Supervisor: PhDr. Mgr. Jiří Kukačka, Ph.D.

Year of defense: 2022

Declaration of Authorship

The author hereby declares that he or she compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain any other academic title.

The author grants to Charles University permission to reproduce and to distribute copies of this thesis in whole or in part and agrees with the thesis being used for study and scientific purposes.

Prague, August 3, 2022

Alexander Macejovsky

Abstract

We contribute to the existing literature on macroeconomic impacts of wage flexibility by examining complexly interacting open economies which undergo economic crises characterized by debt-deflation. More generally, consideration of complexity of interactions and feedback effects between trading countries in our model also constitutes an interesting contribution to the literature on open economies, which usually utilizes small open economy models. We utilize multi-country agent-based model with decentralized markets which produces endogenous economic crises characterized by deflation and excessive levels of private debt. We examine scenarios with different international trade settings and sizes of countries. We find that under almost all scenarios, more stable wages have stabilizing macroeconomic effects as demand-driven recovery is faster and smoother than the one driven by increased margins of firms and consequent debt deleveraging. Moreover, if countries with different levels of wage flexibilities trade with each other, recessions in the country with more flexible wages become milder as international trade helps to increase sales of crisis-hit firms without initiating crisis of a similar severity abroad. Meanwhile, economies of large countries have strong impact on economies of their small trading partners and are considerably more stable. Their firms are in times of crises able to offload excessive supply abroad with considerable negative impact on the small country's firms' sales, while the analogous effects in the opposite case are significantly less powerful.

JEL Classification	F12, F21, F23, H25, H71, H87
Keywords	agent based modelling, international trade, crisis deleveraging, business cycles
Title	Multi-country ABM perspective on business cycles and deleveraging crises

Abstrakt

Prispievame k literatúre zaoberajúcou sa makroekonomickými dopadmi flexibility miezd skúmaním komplexne interagujúcich otvorených ekonomík, ktoré prechádzajú ekonomickými krízami charakterizovými dlh-defláciou. Všeobecnejšie, ohľad na komplexitu interakcií a spätných efektov medzi navzájom obchodujúcimi krajinami v našom modeli predstavuje zaujímavý príspevok k literatúre o otvorených hospodárstvach, ktorá väčšinou využíva modely malých otvorených ekonomík. Využívame viac-krajinný multiagentný model s decentralizovanými trhmi, ktorý produkuje endogénne ekonomické krízy sprevádzané defláciou a vysokými úrovňami súkromného dlhu. Skúmame scenáre s rozlyčními podmienkami medzinárodného obchodu a veľkosťami krajín. V takmer všetkých prípadoch pozorujeme, že stabilnejšie mzdy majú stabilizujúci makroekonomický vplyv, keďže zotavenie poháňané dopytom je rýchlejšie a s menšími prepadmi ako to poháňané vyššími maržami firiem a následným splatením dlhu. Naviac, ak krajiny s rozlyčnými úrovňami mzdovej flexibility obchodujú medzi sebou, recesia v krajine s väčšou mzdovou flexibilitou sa zmierňuje vďaka mediznárodnému obchodu, ktorý pomáha zvýšiť predaj krízou postihnutých firiem bez toho, aby to vyvolalo podobne silnú krízu v náprotivnej krajine. Popritom, ekonomiky veľkých krajín majú silný vplyv na ekonomiky svojich menších obchodných partnerov a sú poznateľne stabilnejšie. Ich firmy sú v časoch krízi schopné predať nadbytočný tovar do zahraničia, čo má poznateľný negatívny vplyv na predaje firiem v menších krajinách. V opačnej situácii je tento efekt podstatne slabší.

Klasifikace JEL	F12, F21, F23, H25, H71, H87
Klíčová slova	multiagentní modelování, mezinárodní obhod, zotavování z krize, ekonomické cykly
Název práce	Ekonomické cykly a zotavování z krize v multiagentním modelu s více zeměmi

Acknowledgments

The author would like to express his gratitude towards PhDr. Mgr. Jiří Kukačka, Ph.D. for his valuable guidance and criticism. The resulting product has been greatly enhanced by them. Any remaining shortcomings are of author's own making. The author is also grateful to doc. PhDr. Zuzana Havránková, Ph.D. and others for their help with certain administrative complications. This thesis is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 681228.

Typeset in LaTeXusing the IES Thesis Template.

Bibliographic Record

Macejovsky, Alexander: *Multi-country ABM perspective on business cycles and deleveraging crises.* Master's thesis. Charles University, Faculty of Social Sciences, Institute of Economic Studies, Prague. 2022, pages 107. Advisor: PhDr. Mgr. Jiří Kukačka, Ph.D.

Contents

List of Tables

List of Figures

Acronyms

ABM Agent-based model/modelling

S-&-S Seppecher & Salle (2015)

JAMEL Java Agent-based Macro-Economic Laboratory

MM medium-medium, model with two medium-sized countries

LS large-small, model with one large and one small country

base baseline parameter setting

alt1 alternative 1; parameter setting with flexible wages

alt2 alternative 2; parameter setting with very flexible wages

Master's Thesis Proposal

Author	Bc. Alexander Mačejovský
Supervisor	PhDr. Mgr. Jiří Kukačka, Ph.D.
Proposed topic	Multi-country ABM perspective on business cycles and deleveraging crises

Motivation Ever since the beginning of the Great Recession examination of economic downturns and optimal policy answers to them has regained the main focus of economists. Moreover, worries about recessions and global crisis have been resurfacing in public discourse in recent times particularly in connection with turbulences in global trade and international trade relations.

The Great Recession inspired large body of research and new developments in economic theory. One of the methods which have gained greater attention from economists during this period is agent-based modelling (ABM). In economics, agent-based modelling is a relatively new method for theory building. One might count among its advantages large complexity achievable by such models as well as wide possibilities for modelling of agents' behaviour and their interaction networks. This enables researchers to apply more realistic behaviour rules and make micro-basis of models more in accordance with empirical findings and experience, which might lead to better predictions. However, large degrees of freedom in models' design and huge complexity are also a major drawback in terms of interpretation and analysis of these models.

In the field of International trade, the use of very popular but relatively simple static models of limited utility has been only slowly complemented by the development of more comprehensive dynamic models (Van den Berg Lewer,2015). Given their complexity and dynamicity, agent based models might emerge as an interesting tool for the research in this field.

In this thesis I will try to use ABM framework to examine economic cycles and crisis propagation in multinational environment. I will transform an agent-based model developed by Seppecher and Salle (2015) into a multi-country one. In this setting I will re-examine effectiveness of demand-driven recovery as opposed to the one driven by debt deleveraging of firms and comment on changes brought by the model's modification. Methods of sensitivity analysis will be of particular interest and their discussion will be one of the contributions of this work. I will also focus on new possibilities offered by this updated model environment, namely effects that trading relations and relative size of economies have on effectiveness of their economic policies. Findings of this part of the thesis are expected to provide insights for policy analysis of open economies and to contribute to examination of the robustness of the previous findings.

I will also use my model to examine how limits put on international trade impact economic development of the involved economies and their business cycles, and the propagation of recessions and recoveries among different countries. Although my modelled international trade environment is expected to be a very simple one, some possibly robust patterns related to response of economic growth to international trade restrictions in affected countries might still emerge thanks to the complexity of interactions of heterogeneous agents allowed by the ABM framework.

Hypotheses

> Hypothesis #1: Demand-driven recovery is faster and smoother than the one driven by increased margins of firms and consequent debt deleveraging even in open economies.
>
> Hypothesis #2: In a situation of frequent trade relations, tested stabilization policies in smaller economies have relatively smaller effects on their own economy than in larger ones. Policies of large economies have spill-over economic effects on their smaller trading partners.
>
> Hypothesis #3: Major constraints on international trade relationships disturb economic cycles and lead to economic recessions in the affected economies.

Methodology Research questions will be examined in context of a multi-country ABM developed on the basis of Seppecher and Salle (2015). Modelling multi-country environment will be inspired by previous works such as Dosi et al. (2019).

Economy of the JAMEL (Java Agent-based Macro-Economic Laboratory) model in Seppecher and Salle (2015) is fully decentralized and stock-flow consistent. The agents of the model include households, firms and a bank. Firms use capital and labour of households to produce a homogeneous product consumed by households. An opinion dynamics model which determines optimistic/pessimistic market sentiments and which leads to large deviations from the steady state and occurrence of endogenous business cycles is also included. The baseline scenario is based on reproducing a set of macro and microeconomic stylized facts. An alternative scenario is then based on increased flexibility of nominal wages.

To augment this basic model into a model of multiple open economies will be the main modelling challenge of the work. The first source of inspiration will be model by Dosi et al. (2019), which includes multiple capital and consumption goods industries, accumulation of technological capital and competition of consumer goods firms on international markets. I will attempt to ignore more complex parts of their model and to follow only construction of international consumption good markets. In these, competition depends on nominal price, which is beside production costs also influenced by exchange rates (endogenous) and trade costs (set as an exogenous parameter).

Calibration of the baseline scenario of the model will be undertaken by the so called Indirect calibration approach in which replication of a set of macro/microeconomic stylized facts by the model will be attempted. Parameter values from the aforementioned studies will be used as starting points. Other multi-country ABMs such as Petrovic et al. (2017), Caiani et al. (2018) and others might also be used for reference in case a need for it has arisen.

Number of countries will be between 2 to 6. This will enable examination of crisis development and policy effects in the multinational context without too high requirements for computational power. In the first setting, 2 economies (large and small one) will be modelled. Next, a world with 1 large and 5 small economies will be considered. Final modelled world will be that of 2 large and 4 small economies.

The first alternative scenario will follow Seppecher and Salle (2015). Other alternative scenarios will focus on impact of trade restrictions. Each time one of the countries in the world will be forbidden to offer its product on international market. Impact of this restriction on growth will be then examined. In case of 6-country world, scenarios with trade blockade defectors – a small country being willing to trade with the blocked one – will be considered, too. Alternatively, manipulations with the cost of trade parameter corresponding to the mentioned scenarios might be considered as well. The results of the simulations will be then contrasted with the predictions of more traditional models of international trade.

Thorough statistical examination of main simulated macroeconomic time series will be part of the model's analysis. Sensitivity analysis will be undertaken on the basis of newest research in the field, such as Broeke et al. (2016).

The model will be written in Java and based on publicly available code of the Seppecher and Salle (2015) model.

Expected Contribution I expect that updating the original paper by Seppecher and Salle into multi-country environment will give new insights into expansion of economic crisis from country to country and to interconnection of business cycles in different economies. Such findings should be relevant especially for countries within multinational economic areas such as the EEA. While there have been some multi-country macroeconomic agent based models, this type of modelled environment seems to be examined much less than more simple closed economy cases. Using a model environment described above will give particular focus on role of market's expectations in development of business cycles in open economies. Results of the model should also provide additional evidence about robustness of the implications of the original model by Seppecher and Salle. Examination of consequences of trade restrictions on economic development in the ABM framework is, to my best knowledge, a novel venture. However, the potential for the use of ABMs in the field of international trade seems to be quite significant, and this work should serve as a step towards this new approach. One of the goals will also be to perform thorough sensitivity analysis, an aspect of models' examination which has been relatively neglected in macroeconomic ABM literature in spite of its importance for comprehension of underlying processes and functioning of the modelled systems.

Outline

1. Introduction
2. Literature review: Discussion of previous research on policies of business cycles stabilization in general and specifically from ABM perspective. Discussion of the previous research on the impact of international trade on the growth and business cycles. Differences between single vs multiple economies models.
3. Model description: Brief description of the original JAMEL model. Description and discussion of the new updates. Description of the different scenarios examined throughout the simulations.
4. Model calibration: Explanation of calibration method, discussion of reproduced stylized facts.
5. Results: Statistical analysis of results. Discussions of model's implications for research questions. Sensitivity analysis and robustness discussion.
6. Discussions: Summarization of findings and ideas for the future research.
7. Conclusion

Core bibliography

Bianchi, C., Cirillo, P., Gallegati, M. et al. Validating and Calibrating Agent-Based Models: A Case Study. Comput Econ (2007) 30: 245.

Broeke, Guus Ten; Voorn, George Van; Ligtenberg, Arend: Which sensitivity analysis method should I use for my agent-based model? Journal of Artificial Societies and Social Simulation 19 (2016)1. - ISSN 1460-7425

Caiani, Alessandro, Ermanno Catullo, and Mauro Gallegati. "The effects of fiscal targets in a monetary union: a multi-country agent-based stock flow consistent model." Industrial and Corporate Change 27.6 (2018): 1123-1154.

Chen SH. (2003) Agent-Based Computational Macro-economics: A Survey. In: Terano T., Deguchi H., Takadama K. (eds) Meeting the Challenge of Social Problems via Agent-Based Simulation. Springer, Tokyo

Dosi, G., Roventini, A. and Russo, E. (2019). Endogenous growth and global divergence in a multi-country agent-based model. Journal of Economic Dynamics and Control, 101, pp.101-129.

Dosi, G. and Roventini, A. More is different ... and complex! the case for agent-based macroeconomics. J Evol Econ (2019) 29: 1.

Delli Gatti, D., Fagiolo, G., Gallegati, M., Richiardi, M. and Russo, A. (2018). Agent-Based Models in Economics. Cambridge University Press.

Grazzini, Jakob (2012) 'Analysis of the Emergent Properties: Stationarity and Ergodicity' Journal of Artificial Societies and Social Simulation 15 (2) 7

Hamill, Lynne and Nigel Gilbert. Agent-based Modelling in Economics. ISBN: 9781118945520; DOI: 10.1002/9781118945520

Petrovic Marko, Bulent Ozel, Teglio Andrea, Raberto Marco and Silvano Cincotti, 2017. "Eurace Open: An agent-based multi-country model," Working Papers 2017/09, Economics Department, Universitat Jaume I, Castellon (Spain).

Macal, C. M. and M. J. North (2005): Tutorial on Agent-based Modeling and Simulation. In Proceedings of the 37th Conference on Winter Simulation, WSC '05, pp. 2-15. Orlando, Florida: Winter Simulation Conference.

Obstfeld, Maurice, and Paul R. Krugman. International Economics: Theory and Policy. Pearson Education, Inc, 8th ed. 2009.

Seppecher Pascal and Salle Isabelle, Deleveraging crises and deep recessions – a behavioural approach, Applied Economics, 2015, Vol. 47 (34-35), pp. 3771-3790,

Singh, Tarlok. "Does international trade cause economic growth? A survey." The World Economy 33.11 (2010): 1517-1564.

Tayebi, Seyed Komail, Zahra Zamani, and Behnam Ebrahimi. "Effects of Business Cycles on Bilateral Trade Flows in Eurozone Countries." International Economics Studies 45.2 (2015): 33-42.

Tesfatsion L., K.L. Judd, edited by (2006). Handbook of Computational Economics, Volume 2, Pages 829-1660, ISBN: 978-0-444-51253-6, ISSN: 1574-0021

Van den Berg, Hendrik, and Joshua J. Lewer. International trade and economic growth. Routledge, 2015.

Author Supervisor

Chapter 1

Introduction

This thesis examines the role of wage flexibility in stabilization of economies in crises. Specifically, we focus on crises characterized by debt-deflation in complexly interacting open economies. For that purpose, we utilize a micro-based stock-flow consistent agent-based model which creates endogenous business cycles.

Notably, Keynes in his *General Theory*, most directly in the Chapter 19 (Keynes 2020), recognized that less flexible wages might be beneficial for economic stability. Before that, classical economic analysis stipulated the role of perfect markets for economic stability and considered wage inflexibilities to be a hindrance for establishing the ideal state of labour market equilibrium. Debates on the role of the wage flexibility on macroeconomic stability have since followed broad lines delimited by these two points of view (Minsky 1975; Gali 2013). Virtues of high wage flexibility are still often deemed as common sense among economic policy circles (Gali & Monacelli 2016; Gali 2013; Eggertsson *et al.* 2014). As wage flexibility can be impacted, for example, through policies regarding labour unions and labour laws, perceived impact of wage flexibility on macroeconomic performance might thus have important real-life consequences.

High levels of debt can have significant impact on development of crises and occurrence of deep recessions. It was Fisher (1933) who, in the midst of the Great Depression, provided first well-known description of connection of high levels of debt and deflation to the deep and persistent economic downturns. These ideas have been later often integrated into Keynes' concept of the liquidity trap (Giraud & Pottier 2016; Pilkington 2014) and overshadowed by neo-classical synthesis, rational expectations and real business-cycles paradigms during the remaining parts of the 20th century (Minsky 1975; Raberto *et al.*

2012; King 1994). They received renewed interest during the fallout of the Great Recession (Shiller 2013), which has been often connected with the high levels of private sector indebtness (see e.g. Cuerpo *et al.* (2015); Justiniano *et al.* (2015)). Works such as Eggertsson & Krugman (2012); Lin *et al.* (2015); Benigno & Romei (2014); Benigno *et al.* (2014); Fornaro (2018), among others, have since striven to enlighten relationship between debt-deflation and economic crises. Such relations can have particular impact on consideration of wage flexibility effects. The latter's virtues are usually connected to decrease of prices which follows from decrease in wage costs. However, deflation increases real value of debts, leading to deleveraging and bankruptcies, which sabotages wage decrease-led efforts to resurrect employment and output back to their normal levels.

There were some efforts to explain international nature of business cycles even during the Great Depression years (Haberler 1936; Neisser 2016). However, the beginnings of the modern research into the links between international trade and GDP co-movements can be traced to Frankel & Rose (1998). Since then, works like De Soyres & Gaillard (2019); Ferrari (2019) have shown systematic links between international trade and GDP correlation of different countries. Works like Gali & Monacelli (2016); Schmitt-Grohé & Uribe (2016); Farhi *et al.* (2014) specifically focus on importance of international trade considerations in examination of macroeconomic effects of wage flexibility. Of particular interest is the competitiveness channel, which stipulates that falling wages will lead to more competitive prices on foreign markets and thus help economy to recover due increased exports.

In the recent couple of decades, agent-based modelling have been gaining more and more interest among the economists. Some of the advantages of this approach are its ability to deal with issues such as endogenous out-of-equilibria dynamics, coordination failures, bounded rationality, and heterogeneity of agents (Gatti *et al.* 2018; Dosi & Roventini 2019). It provides vast range of modelling possibilities, including ability to model agents' behaviour on empirical basis. Its results follow directly from complexity of interactions and are able to capture emergent properties of complex systems. It found considerable success in financial economics, where it can deal with complex patterns in financial markets such as network topologies and information cascade effects (Raberto *et al.* 2012). Some hope that it will replace current mainstream methods in macroeconomics, such as DSGE models (Dosi & Roventini 2019; Gallegati & Kirman 2012).

Still, there are many challenges connected to the methodology, such as interpretation of simulation dynamics and results generalization (Leombruni & Richiardi 2005), validation and reproducibility (Gatti *et al.* 2018; Dosi & Roventini 2019), and difficulties concerning choice of the design of a model in presence of often innumerable modelling possibilities.

Agent-based modelling is often associated with the concept of stock-flow consistency. This emphasizes importance of comprehensive integration of all stocks and flows of the system in order to ensure there are no unaccounted leakages which might affect the system behaviour (Caiani *et al.* 2018; 2016).

We utilize a stock-flow consistent agent-based model to bring together debt-deflation crises and open, complexly interacting economies, in examination of wage flexibility impacts on macroeconomic stability and crises severity. To our knowledge, this is the first attempt to connect all of these factors together. Moreover, the nature of our model leads to complex feedback effects between trading partners, a characteristic often lacking in the literature on open economies. The latter usually utilizes small open economy models which have no or only very limited effects on the rest of the world.

We follow in tracks of Seppecher & Salle (2015), who developed the JAMEL[1] model, a stock-flow consistent agent-based model of a skeletal one-sector economy with numerous firms and households and decentralized labour and final goods markets. Characteristic attributes of its output are alternating states of economic stability and debt-deflation crises.

We augment JAMEL into a 2-country model with international environment inspired by Dosi *et al.* (2019). Our model reproduces alterations between economic crises and stability, which enables us to examine impact of different wage flexibilities on the severity of crises that are characterized by deflation and high indebtness of firms in the environment where international trade impacts sales of firms. We create different scenarios by alternating between low, medium and high wage flexibility of countries. Moreover, we examine robustness of our results to different levels of trade costs and quotas, as well as to the monetary union between the countries. All of this is performed for settings with the same sized countries and settings with one large and one small country.

We analyse the model by performing numerous simulation runs with different random seeds. Our results suggest that less flexible wages have stabilizing effects on economies as they lead to less deep recessions. Even countries with more flexible wages are able to recover from crises more smoothly if they trade

[1] Java Agent-based Macro-Economic Laboratory

with a country that has more stable wages. These results are fairly robust across different trade settings. If one of the countries is considerably smaller than the other one, its economy is due to trade more volatile and goes through deeper recessions in comparison with the situation of two equally sized countries.

The thesis is structured in the following manner: Chapter 2 provides literature review on previous attempts to model macroeconomic impacts of wage flexibility and debt-deflation crises. We also discuss some of the connections between international trade and business cycles and review original results in the Seppecher & Salle (2015) paper. Chapter 3 offers description of our model and simulated scenarios. Chapter 4 provides discussions of our results and Chapter 5 concludes.

Chapter 2

Literature review

We examine existing literature on impact of wage flexibility on macroeconomic stability, firstly by focusing on the debate along the lines of classical versus Keynes' views and then by considering issues of open economies. Next, we discuss literature on debt-deflation crises. Finally, we summarize main findings from the 1-country JAMEL model.

2.1 Macroeconomic effects of wage flexibility

2.1.1 Keynes vs classics

In the "classical" theory of employment as understood by Keynes,[1] the analysis of wage flexibility effects on macroeconomic stability is straightforward. Labour supply schedule is determined by the trade-off between real wages and opportunity costs of labour faced by the workers, in which amount of labour is increasing with wages. The labour demand schedule is given by the equality of real wages and marginal product of labour, which is a corollary of firms' profit maximization under perfectly competitive markets. Given that the marginal product is decreasing as the amount of labour increases, the amount of labour in labour demand schedule is decreasing as real wages rise. The final levels of labour and wages are determined by equilibrium of the labour market, in which the labour supply schedule intersects the labour demand schedule.

The employment is thus dependent on real wages. Only voluntary unemployment, which is caused by opportunity costs of labour prevailing over given wage level, is possible in the equilibrium. Involuntary unemployment, that is

[1] Keynes based his summary of "classical" analysis on Pigou (1933); for a dissenting view on what is "classical" analysis of employment, see e.g. Hicks (1937)

labour demand being lower than its equilibrium value, is explained as the consequence of artificially high wages not being allowed to fall to their equilibrium value due to restraints such as minimal wage laws or labour union pressures. Hence, higher the wage flexibility, the quicker the return of wages and employment from an out-of-equilibrium state to their equilibrium values.

In contrast, Keynes' analogue to the previous in his *General Theory* (Keynes 2020) can be summarized as follows: Keynes formulates output as a function of effective demand. Output, in turn, determines labour demand of firms. Firms are price-makers and they determine nominal prices as function of nominal wages, marginal product of labour and desired mark-up. Here, it is assumed that nominal prices change proportionally to nominal wages. From this, real wages can be considered as function of mark-up and marginal product of labour, independent of nominal wages. Since real wages are positively related to marginal product and the latter is still assumed to decrease in amount of used labour, the real wage will decrease as employment rises. Note that real wages can be thus seen as dependent on employment, not vice versa as in the classical case.

The labour supply schedule can be formulated as in the classical case. Its inverse thus gives real wage demanded by workers for given amount of supplied labour and is increasing in the latter. We can define labour market equilibrium analogously to the classical case as the point where real wage and employment levels equate real wage schedule as determined by employment through marginal product of labour and the inverse of labour supply schedule.

However, labour demand as determined by effective demand is not necessarily equal to this equilibrium value of employment, nor is there any direct automatic adjustment mechanism which would ensure it will become so. Lower than equilibrium level of labour demand will lead to higher than equilibrium level of real wages and involuntary unemployment. Persistent involuntary unemployment becomes possible and the most direct way of its elimination lies in shifting effective demand, e.g. by fiscal or monetary policy, to the level which will correspond to the labour market equilibrium. Nominal wages and their flexibility are not directly relevant for elimination of unemployment.

In more detailed analysis, Keynes examines impact of flexible nominal wages on effective demand, mainly through their effects on propensity to consume, marginal efficiency of capital, and interest rates. These are not necessarily stabilizing. Keynes even argues that, due to psychological, social, and real-debt burden considerations, it is probably more desirable to keep nominal wages inflexible. For a more detailed version of the above summary, see Book 1 and chapter 19 in Keynes (2020) or, more concisely, Gali (2013).

Arguably, more influential for development of mainstream macroeconomics than the *General Theory* directly itself were its interpretations such as Hicks (1937) and Alvin (1953). Some argue that these interpretations ignored some crucial aspects of Keynes' work and were in spirit more close to the classical theory with relatively minor modifications, see e.g. Minsky (1975). Specifically, discussions of the role of nominal wage and price rigidities often degraded them to little more than useful tools for introduction of market imperfections and real effects of monetary shocks into a model De Long & Summers (1985). Nonetheless, these interpretations became integral parts of the Neoclassical synthesis and, later on, New Keynesian models, perhaps the most mainstream tools of today's macroeconomics.

Among more recent literature on the macroeconomic role of wage flexibility, Shimer (2012) finds that wage rigidities cause persistent, but not permanent, decline in growth of employment, output, and other macroeconomic variables in a neoclassical growth model.

On the other hand, Bhattarai *et al.* (2014) build on De Long & Summers (1985) and corroborate latter's findings that, under certain types of shocks, higher wage flexibility can, in tandem with price flexibility, cause significant increase in macroeconomic instability. Moreover, they conduct a counterfactual exercise with a DSGE model showing that full price and wage flexibility would lead to considerably larger volatility of the US output in the post-World War II period than in reality.

Stockhammer & Onaran (2012) use Kaleckian model to demonstrate possible negative effects of wage flexibility and argue against it in the context of European Union. For more on Kalecki's ideas on the problem of wage flexibility, see also López (2020).

Gali (2013) use a New Keynesian model to show that higher wage flexibility does not have always positive effects on the welfare losses from various macroeconomic shocks, though they still find its robustly positive effects on employment and output. In their model, nominal wages have, as was one of the suggestions by Keynes (see above), indirect impact on aggregate demand through their influence on interest rates. Specifically, interest rates follow response of monetary policy to changes in expected inflation initiated by altered wages. The authors highlight importance of monetary policy specifications for the role of wage flexibility.

In our discussion, we have been so far concerned by the case of a closed economy. But international trade and exchange rates can have a significant influence on the macroeconomic effects of wage flexibility, an issue we now turn our attention to.

2.1.2 Open economy considerations

The basic logic of foreign trade effects of falling nominal wages is that when a country engages in international trade, its falling domestic wages would lead to lower prices of products and thus, given no changes in prices of foreignly produced goods or exchange rates, higher exports. This would stimulate domestic economy and strengthen the case for more flexible wages.

Complementary to this, Friedman (1953) points out that floating exchange rates can serve as a channel for relative depreciation of currencies of relatively less competitive countries, which would have similar price effects as falling nominal wages. Floating exchange rates can be therefore compensatory for wage rigidities. Flexible wages would be therefore especially beneficial for members of monetary unions or currency-peg systems. In similar fashion, Schmitt-Grohé & Uribe (2016) show how disequilibrium effects of nominal rigidities in open economies can be remedied by exchange rate devaluation. Farhi *et al.* (2014) adds to this possible solution of nominal rigidities effects in open economies by fiscal policies in situation when exchange rate devaluation is not possible.

In contrast to this, Gali & Monacelli (2016), in the follow-up to Gali (2013), find that effects of reducing costs through wages on employment are much smaller in a currency union than in economies with independent monetary policy and price stability mandate. Their findings again hinge on monetary policy channel. Under hard peg, in the absence of capital controls, domestic interest rates will not deviate from their foreign counterparts. This causes monetary policy channel to be muted, and thus also the effect of labour costs on aggregate demand and employment. The authors also note that, in their model, higher wage flexibility often reduces welfare, though it is more likely to have positive effects if accompanied by increase in price flexibility.

Regarding influences of international trade on economic growth more generally, exploring these connections have proven to be a complex task. There have been many factors proposed as links between trade and growth. Gains from ability to specialize in production, effects of increased competition on firms' productivity and goods' prices, increases in investments and capital stock, firms' learning by exporting and/or importing are among trade's consequences listed as possibly conducive to growth (Singh 2010; Wagner 2012). Moreover, there is an acknowledgement that the relationship between trade and growth is likely to be conditional on issues like endowment differences, aggregate trade volumes, market sizes, ability of innovations and knowledge acquisition, and others (Eicher & Kuenzel 2016).

Theoretical consensus on the impact of international trade on growth has been lacking (Melitz 2003). The Neoclassical Trade and New Growth theories support while New Trade theory is dubious about positive effects of trade on growth (Singh 2010). Empirical literature provides no more clarity. Difficulties in finding appropriate instrumental variables for disentangling trade effects from other closely connected economic dynamics, partly since trade reforms are often accompanied by wide and comprehensive reforms in other areas, and problems with identifying causal direction of correlations, are the main source of ambiguity in empirical research on growth effects of trade (Singh 2010).

2.2 Fisherian debt-deflation recessions and deleveraging

The notion that excess of debt in connection with deflation is the major reason for deep recessions first gained attention through Irving Fisher's Debt-Deflation Theory of Great Depressions (Fisher 1933). The core of the theory is emergence of vicious cycle between deflation and a need to deleverage private debt of firms. At some point, high indebtedness leads to the efforts to deleverage. Paying back debts leads to decrease of money velocity. Given exchange equation

$$MV = PQ$$

where M is money supply, V is velocity of money, P is price level and Q is output, this leads to fall in prices. The corollary is contraction of profits, output and employment, leading to fall in demand and business confidence, and to hoarding of the currency and more deflationary pressure. But deflation also raises the real value of debts, hence efforts to deleverage only lead to higher real indebtness, more efforts to deleverage and initiation of a downward spiral.

The most prominent post-war effort to explain how high indebtedness in a capitalistic economy occurs in the first place has been Hyman Minsky's Financial Instability Hypothesis (Minsky & Kaufman 2008). In Minsky's view, the periods of economic stability foster financial innovations and high confidence in the ability of businesses to repay debts as deemed both from the side of businesses and of that of financial institutions. Consequently, the margins of safety are lowered and there is an increase in what he calls speculative and Ponzi financing – financing by ever more borrowing and refinancing without the ability to pay back the principal or, in the later case, even the interest from the usual cash flow receipts. Such financing is vulnerable to changing financial market conditions and under unfavourable circumstances, what has been dubbed a 'Minsky moment', will lead to, in absence of rescue by government and/or central bank interventions, scaling back of the production, selling of the non-production assets, defaults and bankruptcies or similar contractionary measures.

In the mainstream macroeconomics of the latter half of the 20th century, debt and monetary factors fell out of the focus as neoclassical synthesis, rational expectations and real businesses-cycles paradigms neglected importance of financial factors (Minsky 1975; Raberto *et al.* 2012). Debt-deflation theory started to regain some interest of economists during 1990s (King 1994), but it received more enthusiastic attention of macroeconomists only in the aftermath of the 2007 housing bubble burst and the Great Recession. Along with it, Minsky's insights into bubbles and debt crises which causes credit and economic contractions also received more prominence in the works such as Eggertsson & Krugman (2012) and Raberto *et al.* (2012).

Eggertsson & Krugman (2012) is the seminal work for recent developments in theoretical research of debt-deflation and private deleveraging crises. Using a New-Keynesian framework in one-period general-equilibrium model with representative agents, they modelled deleveraging crisis among debt-deflation by constraining how much debt can the borrowing agent obtain. Sudden downward shift in this constrain, which in the context represents a Minsky moment, leads to contraction in spending and debt-deflation. At zero interest rate bound interesting properties follow – savings have negative effects on aggregate income, flexible wages lead to higher unemployment, increased productivity might lead to lower output; fiscal spending – temporary as long as deleveraging crisis lasts – does not crowd out private spending and even leads to increase of spending from the side of debtors. Under large deleveraging shocks, higher price flexibility leads to larger input decrease after negative demand shocks as contrary to what is often supposed, since lower prices do not help to increase demand but only raise the real value of debt. Public deficit-financed stimulus can mitigate private debt-driven debt-deflation cycle. Presence of forced deleveraging increases positive effects of expansionary fiscal policies during recession periods, and that in spite of consumers being forward-looking and expecting government spending to be ultimately paid by tax hikes. Ultimately, by avoiding Fisherian debt-deflation, strong fiscal response not only mitigates the effects of the deleveraging shock but decreases the very size of this shock. Important to note is that fiscal policy effects should be much higher if the interest rates are at the zero lower bound than if they are positive.

Benigno *et al.* (2014) built on Eggertsson & Krugman (2012), constructing a multi-period model with heterogeneous risk-sharing among households and financial frictions. They expanded the analysis by considering optimal monetary policy at times of deleveraging crisis and binding zero bound. In their setting, targeting high enough inflation target or aggressive fiscal policy mitigated and reduced duration of economic downturns and deleveraging. They also showed that increased benefits of fiscal policy are connected to higher heterogeneity of risk-sharing among households.

A different look on the fiscal policy impact – examination of fiscal consolidation during private deleveraging period – is taken by Andrés *et al.* (2020). Analogously to aforementioned findings, their model showed that the larger and/or faster fiscal consolidation is, the larger and longer lasting negative impact on the output it has. While the short run impact was rather linear in this regard, it had more than proportionate impact on the output losses in a medium run. Lengths and sizes of crises are somewhat dependent on different ways of consolidations (spending cuts, different tax hikes) and interestingly, labour taxes hikes were an exception from the mentioned findings as, due their inflationary and real-estate prices stabilizing effects, they did actually shorten debt-deflation cycle.

The authors also undertook welfare considerations in their analysis. They find that though debt-constrained households gain more from slower fiscal consolidation, other agents (firms and other households) prefer it, too. Similar findings are provided by Fornaro (2018) on the international level within a monetary union – transfers from creditor to debtor countries mitigated the deleveraging crisis, although unevenly in terms of welfare – indebted countries gained while creditors registered welfare losses.

While for Fornaro (2018) economic effects of deleveraging in a monetary union are in line with the findings mentioned earlier, countries not forming a monetary union show in some respects different results due to effects of international trade. Namely, flexible wages are not found to be detrimental to the recovery as consequent fall in domestic demand for tradable goods in countries experiencing deleveraging crisis is more then offset by increase in demand for their exports by the rest of the world motivated by the fall in their prices. International trade thus plays an important mitigating role. A similar situation arise in the scenario of fixed wages but floating exchange rates. This is in accordance with Benigno & Romei (2014), although the latter suggest the importance of home bias for domestically produced goods in deleveraging countries. In their setting, absence of such bias means absence of a clear impact on exchange rates and thus no mitigating effects through the foreign trade channel.

With regard to influence of exchange rates on economy during private deleveraging, it is noteworthy to mention differences when the debts are primarily denominated in a foreign currency instead of the domestic one. In such case depreciation of home currency leads to rise of value of the debt, which enhances needs to deleverage, further weakens the economy and leads to even more depreciation, similarly as in Fisherian debt-deflation vicious cycle. Benigno & Romei (2014) dedicate part of their analysis to the situation when debts are held in a foreign currency. The main difference in optimal policies is intuitively straightforward – while interest rate in the deleveraging country can be now left to rise, foreign interest rate should be lowered to zero.

Previous attempts in the field to examine private deleveraging in international context through ABM approach are Raberto *et al.* (2012) and Chiarella & Di Guilmi (2017). The former strive to better understand effects of debt on the economy. The results of their simulations are by large in line with the main contours of Minsky's financial instability hypothesis – firms receive short-term gains from debt accumulation but increased leverage leads to waves of bankruptcies and credit contraction. Meanwhile, pressure on wage raise leads to inflation and higher interest rates, hence complicating situation of indebted firms which are thus motivated to leverage even more until their situation becomes unmanageable. Consequent deleveraging pressures sometimes causes even 'good but illiquid firms' to go bankrupt. They detect presence of an optimal level of leverage allowed, as high leverage leads to high instability while low leverage leads to inability of firms to access credit.

Empirical perspective on the relation of deleveraging and economic growth is provided by Chen *et al.* (2015). They focus on private sector deleveraging episodes across 36 countries dating back to 1960. While measuring leverage ratios as ratio of debt to GDP in nominal terms they identify that leverage cycles from peak to peak last on average approximately 19 years with average length of deleveraging being 4-5 years and mostly ending within 5 years. Their careful analysis shows that larger or more intense deleveraging in private non-financial sector is positively related to subsequent medium-term gains in economic growth. On the contrary, a prolonged deleveraging is connected with smaller growth. Unfortunately, in their analysis they are not able to inspect the role of policies and active efforts to reduce the leverage.

2.3 Findings from one-country JAMEL model

In the setting of Seppecher & Salle (2015), downturns follow from the rise in pessimism of households and firms. The former decreases consumption/savings ratio, which leads to decrease in demand. This is followed by fall in profits, thus increasing pessimism among firms. The next steps are decrease of prices and employment, wages and dividends, which lead to even more pessimism among households. This dynamics can be understood as a simplified version of Fisherian debt-deflation vicious cycle.

In simulation runs under the baseline parameter settings, the end of a recession depends on how debt-deflation cycle influences income distribution and dynamics of prices-to-wages ratio. Real wage growth due prices falling quicker than nominal wages makes demand-driven recovery possible much sooner than deleveraging of firms is accomplished. At the end of a downturn, employment starts to increase and real wages return to their long-run level. Only towards the end of a downturn firms start to successfully deleverage their debt. When downturn ends optimistic sentiments start a new positive spiral, leading to increased leverage. This continues until the economy is stabilized. Crucially, at some point the opinion model gives rise to new cycles of pessimism and contraction.

In an alternative scenario, in which nominal wages are much more flexible, they fall too quickly and demand-driven recovery due to increased real wages is not possible. Although income distribution inclines more in favour of profits, which leads to short-run achievement of deleveraging for firms, these successes are short-lived, as decrease in real wages drives decrease in aggregate demand, prices and profits. This means that deleveraging process continues. In the end recessions are much longer and with much higher maximum unemployment levels in the alternative scenario when compared to the baseline.

Chapter 3

Model description and calibration

Our model is an extension of Seppecher & Salle (2015) (S-&-S from now on) "JAMEL"[1] model. Design of our international environment was inspired in part by Dosi *et al.* (2019).

3.1 One-country model

The original model in S-&-S is itself an extension of the model in Seppecher (2012). It is a stock-flow consistent micro-founded agent-based model of a one sector, no-growth economy with decentralized markets, fixed interest rates, and without a government or a central bank. It consists of n heterogeneous households, m heterogeneous firms, and 1 bank. One period in the model is correspondent to one month and most operations are done monthly. Firms produce homogeneous consumption goods using labour and fixed capital. Households provide labour for which they receive wages and, in turn, buy consumption goods. Firms can finance their production by loans for which they have to pay interests. Firm goes bankrupt if it is not able to pay back the loans in due time and is replaced after several periods by a newly formed firm. Bank serves mainly as an accounting unit, its only active role is to pay out dividends from the interest payments it receives. Randomly chosen households are owners of the firms and of the bank and receive dividends from them.

Firms and households engage in labour and final goods markets. Both markets are decentralized and follow tournament selection process inspired by Riccetti *et al.* (2015), i.e. each household is matched with a limited number of firms and chooses the highest wage/lowest price bids, respectively. Labour

[1] Java Agent-based Macro-Economic Laboratory

demand and goods' price of a firm is determined by the level of past sales, while wages change in connection to the vacancy rates.

Finally, firms and households have optimistic/pessimistic sentiments which influence level of their dividends and immediate spending, respectively. These sentiments are partly contagious and it is this feature which brings phenomena of business cycles into the model.

Model thus gives opportunities for examination of endogenously arising business cycles in an environment containing firms that finance their operations by debt. In contrast to most of the literature mentioned in the previous chapter, the model does not control for impacts of fiscal and monetary policies or floating interest rates. The uniqueness of the model stems from decentralized nature of its markets and endogenous creation of the business cycles. The authors of the model consider market decentralization and stock-flow consistency to be particularly relevant for analysis of debt crises, households' savings and consumption, income distribution, and wage and price dynamics.

The validation of the model was performed through the so called Indirect Calibration. This means that output of the model under the baseline scenario reproduced wide variety of more than 20 microeconomic and macroeconomic stylized facts. For instance, profit share of income, average mark-up, variability of output gap, average unemployment duration, distribution of firms' size and households' income, pro-cyclicality of inflation, of changes in inventories, and of money velocity, among other facts observed in the baseline scenario of the model, correspond to the values and stylized facts typically observed in OECD countries. Consumption and output are strongly correlated, with consumption being less volatile, as is the usual case in real economies. See the original S-&-S paper for more details.

We now turn to description of the timing of the events and functioning of the markets, including the key behavioural equations. By index i we denote a household and by index j a firm. Argument t denotes a period. Number in parentheses following a parameter indicates its baseline scenario value and $\lfloor \cdot \rfloor$ denotes floor function. Note that the S-&-S paper contains some simplifications with regard to description of behavioural equations. What we provide is a detailed description of the rules based on the model's code.

Timing of the events

The timing of the model events during a period follows. We also include events which concern our international extension of the model.

1. Firms and banks pay dividends, households and firms update their optimism setting, exchange rates are calculated, expired labour contracts are cancelled.

2. Firms plan their production, including labour demand, offered wages and price of goods, and they finance their production plan by taking new loans, if necessary.

3. Labour markets function. Production of goods is undertaken. Wages are paid.

4. Firms determine their goods supply, households determine their budgets.

5. Goods markets function.

6. Trade costs are distributed to the receiving households. Firms pay their debts and interests on loans.

Labour market

In the labour markets, unemployed households are drawn in a random order. Drawn household then chooses from a randomly chosen set of $g_L(= 10)$ domestic firms the best wage offer. If this offer is at least as high as the household's reservation wage then the offer is accepted. If not then the household remains voluntarily unemployed. If there are no labour offers among the chosen firms then household remains involuntarily unemployed.

Firm j determines its targeted labour as

$$h_j^d(t) = \lfloor K \cdot \Upsilon_j(t) \rfloor$$

where $K(= 10)$ is the number of machines the firm owns,

$$\Upsilon_j(t) = \Upsilon_j(t-1) + \delta_j^h(t)$$

is firm's utilization rate with initial value $\Upsilon_j(0) \sim U(0.5, 1)$ and fulfilling additional condition of $\Upsilon_j(t) \in \langle 0, 1\rangle$, and

$$\delta_j^h(t) = \begin{cases} \alpha_j(t) \cdot \nu_F & \text{if } \beta_j(t) < \dfrac{in^T - in_j(t)}{in^T} \\ -\alpha_j(t) \cdot \nu_F & \text{if } \beta_j(t) < \dfrac{in_j(t) - in^T}{in^T} \\ 0 & \text{else,} \end{cases}$$

where $\alpha_j(t), \beta_j(t) \sim U(0,1)$, $in^T (= 2000)$ denotes targeted inventories, $\nu_F (= 0.1)$ denotes flexibility of utilization rate and $in_j(t)$ are firm's before-production inventories. Note that each machine requires the work of one employee per period. One cycle of goods production is finalized after eight periods of the machine being used and yields 800 units of goods. Use of machines which are further in their production cycle is prioritized.

Let $h_j(t)$ denote number of households employed by the firm j before the labour markets open. Then, if $\omega_j(t) > 0$, the firm posts $\omega_j(t)$ offers to the labour market, otherwise it fires $\omega_j(t)$ employees. The newest employees are fired first. Here,

$$\omega_j(t) = h_j^d(t) - h_j(t).$$

Offered wage of the firm is determined as

$$w_j(t) = (1 + \delta_j^w(t)) \cdot w_j(t-1)$$

with initial value $\omega_j(0) = 3000$, and where $\delta_j^w(t) = 0$ if $\omega_j(t) \leq 0$, else

$$\delta_j^w(t) = \begin{cases} \widetilde{\alpha_j}(t) \cdot \widetilde{\nu}_{F\_up} & \text{if } \widetilde{\alpha_j}(t) \cdot \widetilde{\beta_j}(t) < \dfrac{\rho_j(t) - \rho^T}{\rho^T} \\ -\widetilde{\alpha_j}(t) \cdot \widetilde{\nu}_{F\_down} & \text{if } \widetilde{\alpha_j}(t) \cdot \widetilde{\beta_j}(t) < \dfrac{\rho^T - \rho_j(t)}{\rho^T} \\ 0 & \text{else,} \end{cases}$$

where $\widetilde{\alpha_j}(t), \widetilde{\beta_j}(t) \sim U(0,1)$, $\widetilde{\nu}_{F\_up} (= 0.06)$ and $\widetilde{\nu}_{F\_down} (= 0.09)$ are firm upward and downward wage adjustment parameters, $\rho^T (= 0.03)$ is the targeted vacancy rate, and

$$\rho_j(t) = \frac{\sum_{i=1}^4 \varphi_j(t-i)}{\sum_{i=1}^4 h_j^d(t-i)}$$

is firm's 4-period vacancy rate. Here, $\varphi_j(t)$ denotes number of vacancies, i.e. unsuccessful labour offers, and $h_j^d(t)$ is firm's targeted labour (see above). Initially, we put $\rho_j(1) = 0$.

Reservation wage of a household i is determined as its current received wage if it is employed, else as

$$\widehat{w_i}(t) = (1 - \delta_i^{Hw}(t)) \cdot \widehat{w_i}(t-1) \tag{3.1}$$

where

$$\delta_i^{Hw}(t) = \begin{cases} \alpha_i^H(t) \cdot \eta_H & \text{if } \beta_i^H(t) < \dfrac{d_i^w(t)}{d^w} \\ 0 & \text{else.} \end{cases}$$

Here, $\alpha_i^H(t), \beta_i^H(t) \sim U(0,1)$, $\eta_H (= 0.05)$ is wage plasticity parameter, $d^w (= 12)$ is wage resistance parameter and $d_i^w(t)$ is number of periods the household has been unemployed. Initial reservation wage is 0. Note the importance of the equation 3.1 for our analysis as the wage flexibility and wage resistance are parameters that we vary across different wage flexibility scenarios (see section 3.4 below).

Goods market

In the goods market, households are drawn in random order. Out of the firms which are allowed to offer goods on the drawn household's domestic market, the household randomly chooses $g_G (= 15$ in 2-country models) of them. It then buys the cheapest offers until it either runs out of its budget or buys all of the goods on the offer.

Initially, goods prices are set to zero. Then, if $p_j(t-1) = 0$ we set

$$p_j(t) = unit_j(t-1),$$

where $unit_j(t-1)$ is the average unit cost of firm's after-production inventories. Otherwise, goods prices are sticky and can be changed only if $d_j^p(t_j^*) \leq t - t_j^*$, where t_j^* is the most recent period when firm j changed its price and $d_j^p(t_j^*) \sim U(0,3)$. If this holds, then

$$p_j(t) = \begin{cases} up_j(t) & \text{if } sales_j(t-1) = y_j(t-1) \text{ and } 0 < \dfrac{in^T - in_j(t)}{in^T} \\ down_j(t) & \text{if } sales_j(t-1) < y_j(t-1) \text{ and } 0 < \dfrac{in_j(t) - in^T}{in^T} \\ p_j(t-1) & \text{else,} \end{cases}$$

where $y_j(t)$ is firm's goods supply (see below),

$$up_j(t) \sim U(p_j(t-1), high_j(t-1)), \qquad down_j(t) \sim U(low_j(t-1), p_j(t-1)),$$

and

$$low_j(t) = \begin{cases} low_j(t-1) & \text{if } d_j^p(t_j^*) > t - t_j^* \\ p_j(t) & \text{if } d_j^p(t_j^*) \leq t - t_j^* \text{ and } sales_j(t-1) = y_j(t-1) \\ (1-\eta_F) \cdot low_j(t-1) & \text{else,} \end{cases}$$

$$high_j(t) = \begin{cases} high_j(t-1) & \text{if } d_j^p(t_j^*) > t - t_j^* \\ (1+\eta_F) \cdot high_j(t-1) & \text{if } d_j^p(t_j^*) \leq t - t_j^* \text{ and } sales_j(t-1) = y_j(t-1) \\ p_j(t) & \text{else.} \end{cases}$$

Here, $\eta_F(= 0.05)$ is price adjustment parameter. To summarize, firm can increase its price by a positive random value only if in the previous period it sold all of its offered goods, its level of inventories is lower then targeted, and the stickiness condition is satisfied. It might lower its price by a random value only if it did not sell all of its offered goods in the previous period, its inventories are higher then targeted, and the stickiness condition is satisfied.

Firm's supply is zero if its goods price is zero, otherwise firm j determines its supply as

$$y_j(t) = \begin{cases} \lfloor \frac{\Upsilon_j(t)}{2} \widehat{inv}_j(t) \rfloor & \text{if } \widehat{inv}_j(t) \leq in^T \\ \lfloor \frac{\Upsilon_j(t)}{2} \widehat{inv}_j(t) \rfloor + \widehat{inv}_j(t) - in^T & \text{else,} \end{cases}$$

where $\Upsilon_j(t)$ is firm's utilization rate (see above) and $\widehat{inv}_j(t)$ are firm's after-production inventories.

Budget of household i is given as

$$c_i(t) = min(c_i^T(t), cash_i(t))$$

where $cash_i(t)$ is cash-on-hand available to the household and

$$c_i^T(t) = \begin{cases} \lfloor (1-\kappa_{Si}(t)) \cdot \overline{inc_i}(t) \rfloor & \text{if } s_i(t) < s_i^T(t) \\ \lfloor \overline{inc_i}(t) + \mu_H \cdot (s_i(t) - s_i^T(t)) \rfloor & \text{else} \end{cases}$$

is household's targeted consumption. Here, $\overline{inc_i}(t)$ stands for household's average income over the past 12 periods, $\mu_H(= 0.5)$ is the rate of consumption of excessive savings, $\kappa_{Si}(t)$ is household's saving fraction, which takes value $\underline{\kappa}(= 0.15)$ for optimistic households or $\overline{\kappa}(= 0.2)$ for pessimistic ones,

$$s_i(t) = \lfloor cash_i(t) - \overline{inc_i}(t) \rfloor$$

are household's current savings and

$$s_i^T(t) = \lfloor 12 \cdot \overline{inc_i}(t) \cdot \kappa_{Si}(t) \rfloor$$

are household's targeted savings.

For details on financial system and bankruptcy process, please see section 3.3. For more details on optimism/pessimism dynamics of firms and households, dividend payments, and motivation for given behaviour rules, please refer to the S-&-S paper.

3.2 International environment

We provide a simple multi-country extension of the original JAMEL model by allowing firms to offer their goods on foreign markets. We inflate price of foreign goods by international trade costs and amount of foreign firms allowed to trade is limited by trade quotas.

We reproduce the design of exchange rates and goods prices from Dosi *et al.* (2019). The exchange rate equation between countries u, v is

$$e_{u,v}(t) = \frac{e_u(t)}{e_v(t)},$$

where

$$e_k(t) = [1 + \gamma \frac{TB_k(t-1)}{\overline{Y}(t-1)} + u_k(t)] e_k(t-1)$$

and where $u_k \sim N(0, \sigma_e)$ is a white noise component with standard deviation $\sigma_e(= 0.002)$, $\gamma(= 0.1)$ is the exchange rate regime sensitivity parameter, TB^k is the trade balance of the country k and $\overline{Y}$ is the aggregate worldwide product, both measured as the volume of goods. Initially $\forall k$: $e_k(0) = 1$.

Price of goods offered in country v by firm j, which is located in country u, is then

$$p_{j,v}^u(t) = [1 + \tau_{u,v}] p_j^u(t) e_{u,v}(t)$$

where $p_j^u = p_j$ is the corresponding price on the domestic market determined as in the 1-country model and $\tau_{u,v}$ is the trade cost parameter between the two countries.

We define trade quotas $TQ_{u,v}$ as the ratio of firms from the country v allowed to offer their goods in the country u. These firms are drawn randomly once per period. All firms are always allowed to offer their goods on their domestic markets, i.e. $TQ_{u,u} = 1$.

Each country has also its own bank. Banks and firms have domestic owners, i.e. dividends are paid out to domestic households.

3.3 Financial system and stock-flow consistency of the model

Stock-flow consistency of a model means that sources of all stocks and flows are properly accounted for within the system. There are no artificial leakages to or from the system which might compromise model's interpretation (Caverzasi & Godin 2013). This is ensured in our model by keeping account of all undergoing financial operations on the banks' records.

Financial system of our model can be described by the assets and liabilities of the banks. For simplicity, let's first consider the case of closed economy.

Loans provided by the bank to firms constitute assets of the bank while the funds on bank accounts of firms, households and bank's own account constitute its liabilities. In other words, bank's liabilities are country's money supply. Note that behavioural rules ensure that firms' and households' bank accounts do not decrease below zero, ensuring that there is no economic activity financed by funds not originating from the bank loans. Bank is the sole creator of the money.

New loans constitute increases in the amount of bank's assets and, correspondingly, liabilities, as loaned funds are added to the respective firm's bank account. Principal payments work in the opposite fashion.

In each period, new loans are created when firms need additional funds for fulfilment of their production plan in that period. Additionally, if a firm does not have funds to pay interest on a loan, it borrows the difference between the available and needed funds and the corresponding loan's principal is increased by this amount.

Firm goes bankrupt if its current available funds are insufficient for paying back the principal on any of their loans in due time. In that case, the remaining amount of the debt as well as all other loans of the firm are liquidated by decreasing bank's own funds. Both assets and liabilities of the bank thus decrease by equal amount.

Financial flows in the economy are constituted of the movements between bank accounts of individual agents, i.e. between liabilities of the bank. These include:

- Wages and firm dividends flow from firms to households.
- Payments for goods purchases flow from households to firms.
- Interest payments flow from firms to the bank.
- Bank dividends flow from the bank to its owner's household.

In a model with closed economies, the above embodies all possible financial operations in the model. Thus it is ensured that total assets are at all points in time equal to total liabilities of the bank. This constitutes stock-flow consistency of the model.

In our model of open economies, we need, in addition to the above, account for purchases of the foreign-made goods. Prices paid by purchasing households for such goods have two components: core price component and trade cost component.

Trade costs are received in the import currency by a trade firm, which is owned by a household located in the import country. Trade firms then fully pay received trade costs as dividends to their owners. From this point of view, trade costs are in effect redistribution of funds between households within the same country and have no impact on amount of total assets and liabilities of either country. Since they are fully received by agents of the import country, they can be intuitively understood as trade tariffs.

Core price component moves from the purchasing household's account to the selling firm's account. It decreases liabilities of the import country's bank by amount denominated in import currency and increases liabilities of its counterpart in the export country by amount denominated in the export currency. As the counterpart to this on the assets side, banks keep foreign trade account. Foreign account, and hence assets, of the export country's bank increases by core price component denominated in the export currency while its counterpart on the import country's side does the opposite in import currency. This is akin to the import country's bank taking a loan in export money from the export country's bank (and sending it to the selling firm's account) and receiving in return payback of a loan (funded from the purchasing household's account) in import currency from it.

Total assets and liabilities of both banks are thus kept in balance and the model remains stock-flow consistent. Simple summary of the above for a given bank can be given by the following equalities:

$$\text{total liabilities} = \sum accounts = \sum loans + \text{foreign trade account} = \text{total assets}$$

Note that money supply $= \sum accounts$ is increased by creation of loans and exports and decreased by liquidation of loans and imports.

3.4 Calibration and scenarios

We analyse simulations of models of two open economies. First, we differentiate scenarios by the size of simulated countries. Following S-&-S, in a world with two equally sized countries, for simplicity denoted as **MM** from now on, we allocate 5000 households per country. We also analyse world with a large-small pair of countries, denoted as **LS**, in which case the large country has 8000 households and the small one has 2000 households. We keep ratio of households-to-firms to 100-to-11 as in the original model. See table 3.1 for summary.

Table 3.1: Number of agents based on country size

size	label	no. of households	no. of firms
small	S	2,000	220
medium	M	5,000	550
large	L	8,000	880

We follow S-&-S also in constructing different wage flexibility scenarios. There are two parameters that characterize differences between these scenarios. Wage resistance determines how long a household must be unemployed before it starts to decrease minimum wage it is willing to accept for work. Wage plasticity parameter determines how many per cents a household is willing to decrease this minimum wage per a period of unemployment. See equation 3.1. We vary three wage flexibility settings of countries to construct different scenarios – the baseline setting, the alternative setting with slightly more flexible wages, and the extreme alternative setting with very flexible wages. These settings are again reproduced from S-& -S and its accompanying Java code. See table 3.2 for summary.

Table 3.2: Parameter values in different wage flexibility settings

setting	label	wage resistance	wage plasticity
baseline	**base**	12 periods	0.05
alternative	**alt1**	8 periods	0.08
extreme alternative	**alt2**	8 periods	0.25

In total there are 9 possible ways of how to combine 3 wage flexibility settings across 2 countries. We focus on combinations including at least one baseline wage flexibility setting. We consider scenario with both countries having the baseline wage setting as the baseline scenario. Moreover, for more straightforward comparison with the baseline scenario we also analyse scenarios where both countries have alternative wage flexibility setting. We do not analyse scenarios with both countries having extremely flexible wages as those lead to a similar collapse of the economic systems as was the case in the corresponding scenario in the 1-country model as already depicted in S-&-S. Since under our specifications countries in MM world can differ from each other in their design only due wage flexibility settings, the results of the model are not dependent on order in the combination in these cases. In LS world the results do dependent on whether the large or the small country has given wage flexibility setting.

All in all, these combinations then lead to 4 and 6 different scenarios for MM and LS worlds, respectively. See table 3.3 for summary.

Table 3.3: Wage flexibility settings across evaluated model scenarios

MM world	LS world
base - base	base - base
alt1 - alt1	alt1 - alt1
base - alt1	base - alt1
base - alt2	base - alt2
	alt1 - base
	alt2 - base

Note: For example alt1 - base in LS world means that the large country has the alternative wage flexibility setting and the small country has the baseline setting.

Concerning calibration of the new parameters for international environment, we follow Dosi *et al.* (2019) in assigning values to exchange rate regime sensitivity and standard deviation of the related noise component at $\gamma = 0.1$ and $\sigma_e = 0.002$, respectively. In our exploratory experimentations we discovered that the value of the exchange rate sensitivity parameter does not have significant influence on the output of our model unless driven to very high values (around 0.35 and higher), where it is palpable that impact of response of exchange rates to trade balances on the economy becomes unrealistically strong.

We limit our analysis to considerations of symmetrical trade costs and quotas, i.e.

$$\forall u, v : \tau_{u,v} = \tau_{v,u} = \tau, \qquad TQ_{u,v} = TQ_{v,u} = TQ.$$

In calibrating trade costs, we proceeded by exploring parameter space by grid search in order to determine parameter values which led to simulations producing business cycles – a crucial condition for our goals – and to overall behaviour of the system which was not obviously unrealistic. We determined that relevant values of trade costs lie in $[0, 0.7]$ interval for MM world and in $[0, 0.4]$ interval for LS world. As a starting point of our analysis, we assign the baseline trade costs value of $\tau = 0.02$ for both MM and LS worlds. We then expand our analysis by considering border values of the aforementioned intervals.

Similarly, we consider low, medium, and high values of trade quotas. As baseline we allow all firms to participate in all goods markets, i.e. we put $TQ = 1$. See table 3.4 for summary.

Note that non-linear choice of parameter values reflects non-linearity of changes in our model's behaviour with regard to changes in trade costs and trade quotas as demonstrated by our exploratory analysis. We consider these choices of values as well representative of those changes.

Table 3.4: Trade costs and quotas values for evaluated scenarios

	trade costs τ	trade quotas TQ
high	0.7 (0.4)	1
medium	0.2	0.3
low	0	0.05

Note: Value in parentheses show high trade costs in LS world scenarios. Other values are identical in both MM and LS worlds.

In Chapter 4 we make extended analysis of the results from scenarios with the baseline international trade costs and quotas settings for both MM and LS worlds and across all wage flexibility settings summarized in table 3.3. We then briefly comment on the sensitivity of our results to changes in international trade costs and quotas. Finally, we also briefly comment on how a monetary union between countries alter results under the baseline trade costs and quotas.

Chapter 4

Results and discussions

In this chapter we offer analysis of the results of the performed simulations. We focus mainly on the baseline international trade costs and quotas settings. In these cases the results are based on 101 simulation runs across all wage flexibility scenarios, with each run within a scenario being provided with a unique random seed. Other scenarios serve mainly as robustness checks on the results drawn from the baseline scenarios and due practical considerations of available time and digital memory we limited we performed only 61 unique simulation runs for the scenarios with the baseline trade costs but bounding trade quotas limitations and 31 unique runs for scenarios with high or no trade costs. Nevertheless, given relatively low variance of the obtained results, we believe that even only 31 simulation runs provide quite robust information about respective scenario.

Each simulation run is 1500 periods long. However, firms are not allowed to go bankrupt in the first 120 periods of a simulation. These initial 120 months are thus considered to be the burning-in phase and are not accounted for in the analysis of the results.

Due to personal preferences we developed our models in Python instead of building on the existing Java code of the JAMEL model. We thus begin by a brief comparison of our replications of 1-country models with the results provided in the S-&-S. We then proceed with description of our approach to the results' analysis, including definitions of the measures we use for judgement of economic performance of simulated economies. We then first analyse results of the MM scenarios and then proceed with the analysis of LS scenarios' results. We conclude by discussions of the place of our model within the existing literature and of potential future developments.

Table 4.1: Reproduction of Table 2 from S-&-S

data	S-&-S values	author's values
unempl. rate (mean)	0.0909 (0.0020)	0.0902 (0.0031)
unempl. duration (months)	2.2188 (0.0155)	2.2000 (0.0230)
inflation (yearly, mean)	0.0308 (0.0006)	0.0282 (0.0012)
inflation (yearly, std)	0.0490 (0.0029)	0.0266 (0.0036)
markup	0.3330 (0.0092)	0.5042 (0.0188)
profit share	0.3300 (0.0091)	0.3373 (0.0088)
velocity of money	3.6400 (0.0276)	3.6000 (0.0263)

Note: Average over 61 runs, standard deviations in parenthesis.

4.1 Notes on replication of 1-country models

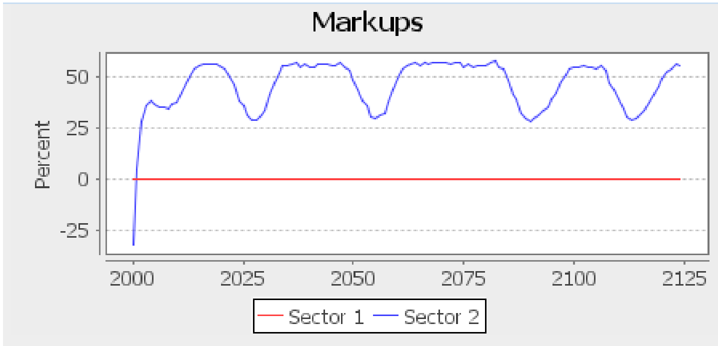
We used behavioural and market rules and timing of the events as occurring in the original Java code[1] of the S-&-S model for remaking the model from the scratch in Python. To show that this has been done accurately we provide following tables and figures produced by our version of the model which can be compared to results provided in the S-&-S paper. Note that we used 61 different simulation runs while S-&-S reported using only 30 simulation runs. Moreover, we have not found information about length of individual simulation runs used by S-&-S, whether they accounted for burning-in period, or whether they calculated reported statistics based on the whole simulation, including crises periods, or only on the stability-area periods. These might be the causes of some deviations between their and our results.

Table 4.1 replicates Table 2 from S-&-S. Most of the presented data are very close to that presented in the original table. We see notable differences in mark-ups values, which might be caused by aforementioned factors or differences in definitions. Time series of mark-ups received from the JAMEL application do not significantly differ from those obtained from our simulations, see e.g. figures 4.1 and 4.2. We obtain slightly lower levels of inflation, which seem to be a real difference between original model and our replication. We have not found the cause of this inconsistency but, given small differences in all of the other obtained results, we consider this issue to be of negligible consequence for our purposes. Also note that we report on average standard deviation of yearly inflation, while Table 2 in S-&-S claims to report on its average variance.

[1] the JAMEL application is available on
`https://www.dropbox.com/s/5od2oby9ybaes7m/jamel_AE2015.zip?dl=0`
the codes can be obtained by unpacking the application

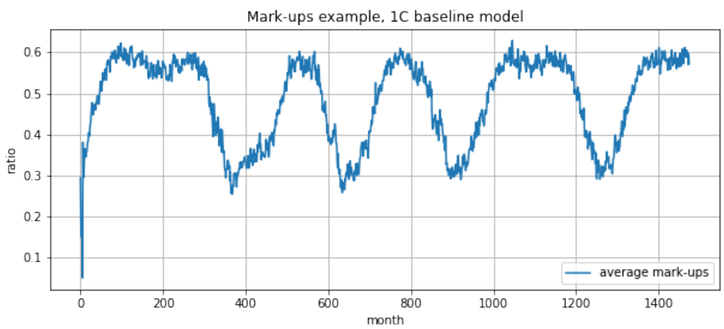
The latter seems to be an oversight as the levels of average inflation variance as reported would be suspiciously high.

Figure 4.1: Original JAMEL mean mark-ups



Note: Example of baseline scenario time series of mean mark-ups from the original JAMEL application. Labels on x-axis represent years with the beginning in 2000.

Figure 4.2: Mean mark-ups time series, author's results



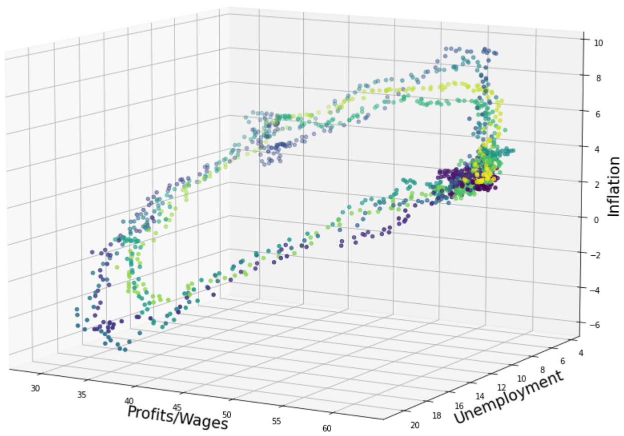
Note: Example from 1-country baseline scenario

Figure 4.3 replicates figure 2.(a) from S-&-S. Note that we use data from different simulation run, hence the replication is only approximate. The general shape and range of the provided 3D projection are in correspondence with the original figure.

By comparing output from the original JAMEL application and corresponding time series obtained from our model we see that, apart from slightly lower inflation in our model, which over time results in comparatively lower nominal values of variables, there are no significant differences in the behaviour of the models. See figures B.1 and B.2, B.3. Compare these also with Fig. 4 in S-&-S.

We obtain similar correspondence of outputs for alternative scenarios with more flexible wages.

Figure 4.3: Reproduction of Fig.2.(a) from S-&-S



Note: Match is only approximate as we used data from different simulation run.

4.2 Approach to analysis of results

Our main focus is on the development of economic crises. In the outputs of our simulations, employment rates are much less noisy than other measures of economic activity, e.g. production. Furthermore, as there is no economic growth and productivity is fixed and homogeneous, we deem it appropriate to focus on the evolution of the employment as the main measure of the economic activity.

As was the case with the 1-country version of JAMEL model, characteristic feature of the dynamics of our models is that there are periods of stability when employment rate oscillates within a narrow area around its long-term average alternating with periods of crises, when unemployment sharply increases. Inspired by this fact, for a given scenario and country we first try to find the lower boundary of the area of stability of employment rate, denoted as L. Based on visual inspection of the results, our first intuitive inclination is then to use the first quartile of employment rate per a simulation as the lower boundary of the stability area.

Since these value can vary widely across simulations within a scenario, for example due to different number of crises during a simulation, we average them to obtain L for a given scenario and country as

$$L = \sum_{s=1}^{S} \frac{Q1_s^{empl\_rate}}{S},$$

where $Q1_s^{empl\_rate}$ is the first quartile of the employment rate during simulation s and S is number of simulations performed for the given scenario. L value is thus given as a unique value for given scenario and country. This is in accordance with a more philosophical considerations of regarding areas of stability as property of the given parameter setting rather than of an individual random simulation.

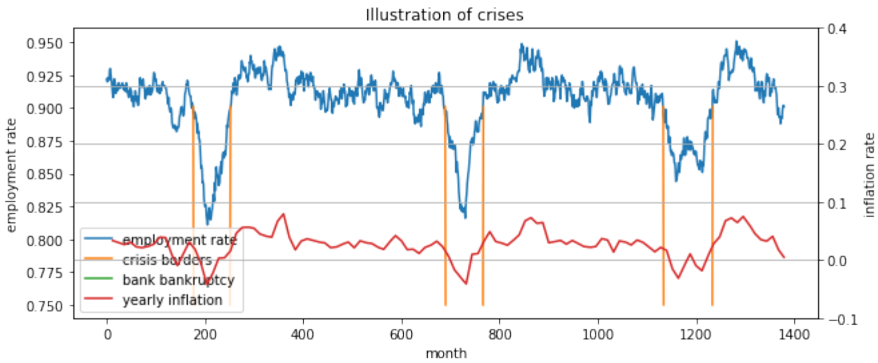
Next, we define economic crisis of a country as an uninterrupted series of periods during which the employment rate of the country is bellow the corresponding L value while a minimal crisis depth condition is met. The latter requires that the bottom of the crisis in terms of employment rate is at least c percentage points below the L value. This is required in order to avoid classifying occasional mild deviations from the area of stability as crises. In summary, L value determines start and end points of a crisis, while c value serves as a filter of false signals.

Too small c might results in too many false signals and lower average crisis bottoms (and vice versa for number of crises). We strived to find c value such will satisfy our intuitive perception of what is a true crisis and what is only an insignificant deviation from the stability area. We decided to put $c = 3$ for all scenarios and countries. Note that this value is about 2 to 3 average standard deviations of employment rates observed during non-crisis periods across most scenarios, where crises are determined by these choices of L and c. Therefore, we believe it should account for small deviations from the area of stability without being too restrictive.

Although these choices might seem rather arbitrary, our main goal is to establish measures for comparison of economic performance in different scenarios. Our definition of the economic crisis serves this purpose well and it captures our intuitive understanding of what a crisis should be in our simulated economy. For illustration, see figure 4.4.

We use asymptotic t-tests for testing statistical significance of differences between the L values and means of average crisis bottoms/lengths of different countries. Specifically, we use pairwise t-tests if we compare data from country 0 and country 1 from the same scenario, and Welch t-tests (2-sample t-tests without the assumption of the variance equality between the samples) if we

Figure 4.4: Example of economic crises in the model



Note: Time series of monthly employment rate and yearly inflation rate from a simulation of MM scenario with the baseline wage and trade settings.

compare countries across different scenarios. We take average of crises bottoms and lengths, respectively, of a country per simulation as our random variable so as to ensure independence of observed random sample (subsequent bottoms/lengths in a simulation might not be mutually independent) and correct pairing of observations for pairwise t-test.

For measuring business cycles synchronization, we use, apart from temporal cross-correlations of different macroeconomic time series across countries, minimal rate of crises intersections, that is, for countries u and v,

$$BCsync_{u,v} = BCsync_{v,u} = min\{BCsync^{u}_{u,v}, BCsync^{v}_{v,u}\},$$

where

$$BCsync^{l}_{l,k} = \sum_{1}^{T} \frac{\chi_{l,k,t}}{CrTime_l},$$

where T is total length of the simulation, $CrTime_l$ is total time country l spend in crises during the simulation, and for period t and countries l and k

$$\chi_{l,k,t} = \chi_{k,l,t} = \begin{cases} 1 & \text{if both countries are in crises} \\ 0 & \text{otherwise.} \end{cases}$$

See appendix A for additional comments on the analysis approach.

4.2.1 Definitions and notations in reported tables and figures

In reported box-and-whiskers figures, box extends from the first to the third quartile of the data. The coloured line inside the box represents the median.

The whiskers extend from the box by 1.5 multiple of the inter-quartile range or to the data extremes, whichever is closer to the box. Circles represent data-points beyond the whiskers' borders.

In order to avoid confusion, we emphasize that in tables with descriptive statistics and box-and-whiskers figures we utilize data for individual crises, while for t-tests we use per-simulation averages across crises.

In the presented tables we refer to the $BCsync$ metric as the BC metric. Crisis bottoms are measured as the lowest observed employment rate during the crisis. When we report descriptive statistics of a variable, we first measure its average value in each simulation of a scenario and then report descriptive statistics of thus obtained set of these averages. We also measure standard deviation of the variable for each simulation and report mean and standard deviation of these standard deviations across all simulations of a scenario. The latter two are referenced in the tables as "inner std" and "std of inner std".

We use zero-based numbering in denoting the first country in the model as C0 and the second one as C1. Models and scenarios are referenced by their names and labels as summarized in section 3.4 and tables 3.1, 3.2 and 3.3. We sometimes refer to scenarios where both countries have the same wage flexibility settings as the same wage scenarios and scenarios where one country has the baseline wage flexibility setting and the other has alternative or extreme alternative wage flexibility settings as mixed wage scenarios. We refer to situation when both countries are in a crisis at the same time as a global crisis.

Note that we report (un)employment rates without distinction between voluntary and involuntary unemployment. Voluntary unemployment usually oscillates in $8-12\%$ range.

4.3 Models of two medium-sized countries

In this section we present analysis of models with two medium-sized countries, labelled as MM models.

We begin by discussion of scenarios with baseline trading settings, i.e. with medium trade costs, no binding trade quotas and floating exchange rates. Under these settings we vary between the baseline, i.e. low (base), medium (alt1) and high (alt2) wage flexibility for a country to get four scenarios - one with both countries with inflexible wages (base-base), one with both countries having moderately flexible wages (alt1-alt1), and mixes of a country with inflexible wages with a country with moderately (base-alt1) or highly flexible wages (base-alt2), respectively. Firstly, we present comparison of our 2-country systems vis-à-vis 1-country model in order to comment on replication of stylized facts and basic impacts of introduction of international trade. We then discuss properties of individual scenarios one by one before making comparative analysis of them.

Lastly, we comment on how the outcomes of these four scenarios are impacted by pegging exchange rates at parity, i.e. by monetary union, and by changes in trade quotas and costs.

4.3.1 Basic trade settings

Comparisons with 1-country models

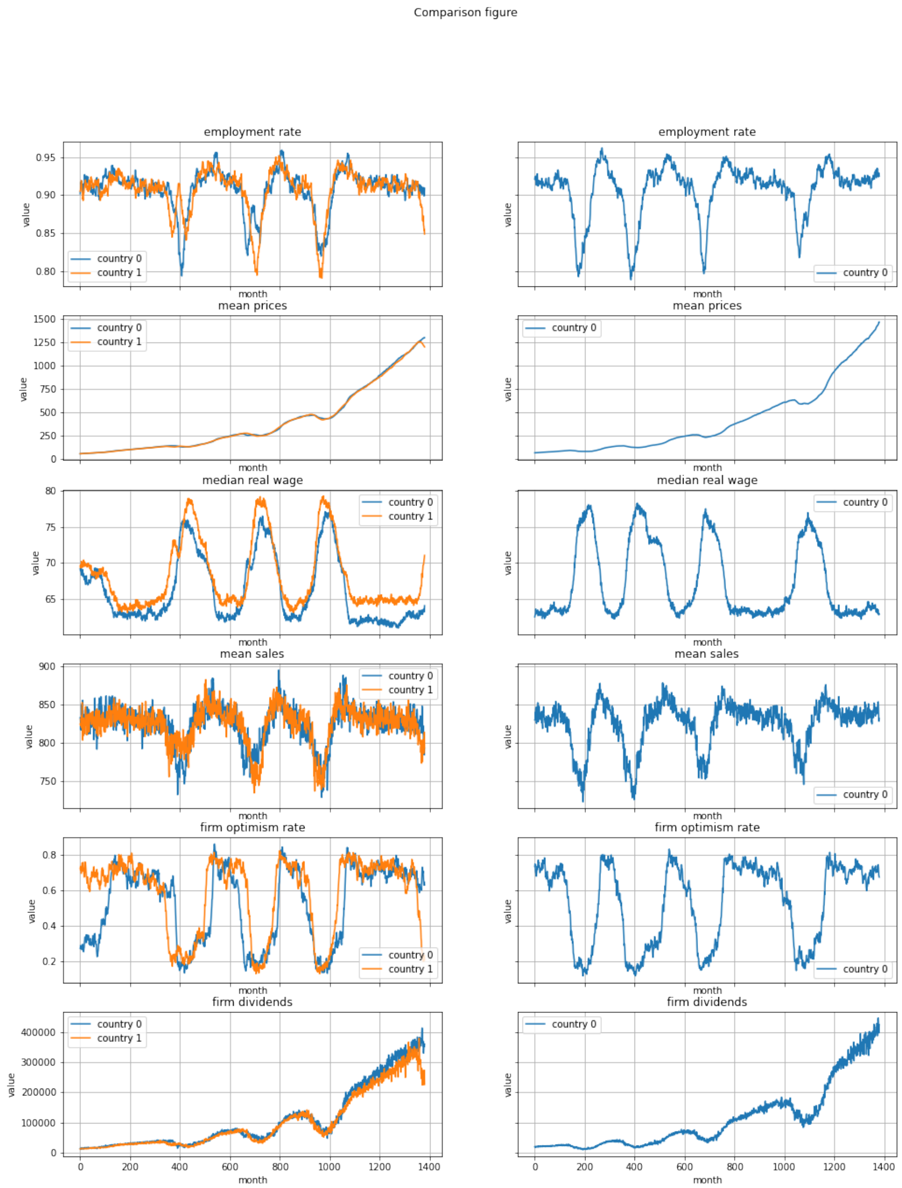
The baseline scenario of the original 1-country model in S-&-S is calibrated with the aim of reproducing number of economic stylized facts. We do not test for replication of these stylized facts in our simulations. Instead, we point to the fact that our base-base economic systems exhibit behaviour which is very similar to the baseline 1-country model. For illustration we offer figures 4.5 and B.4 showing side by side number of macroeconomic time series from a simulation run of our base-base scenario and the baseline 1-country scenario. Most of the macroeconomic variables show similar behaviour across the two models, though we can observe slight differences. For example table 4.2 provides descriptive statistics for yearly inflation in both scenarios with the baseline and slightly flexible wages. This indicates that although general behaviour of the systems remain analogous to the 1 country model, there are some differences resulting from the introduction of the international trade.

Table 4.2: Summary statistics of inflation in 1-country model and MM model

	min	mean	max	std	mean inner std	std of inner std
base-base						
country 0	2.38	2.66	2.88	0.1	2.54	0.35
country 1	2.42	2.66	2.91	0.1	2.53	0.37
1-C model base						
country 0	2.49	2.82	3.08	0.12	2.66	0.36
alt1-alt1						
country 0	0.71	1.19	1.59	0.18	3.30	0.21
country 1	0.75	1.20	1.61	0.18	3.27	0.20
1-C model alt1						
country 0	0.75	1.31	1.91	0.24	3.18	0.26

Note: Statistics of yearly inflation rates, values represent per cents. Columns 2-5 report descriptive statistics of datasets in which individual data points represent averages of respective time series per simulation. Columns 6 and 7 display means and standard deviations of datasets in which individual data points represent standard deviations of respective time series per simulation.

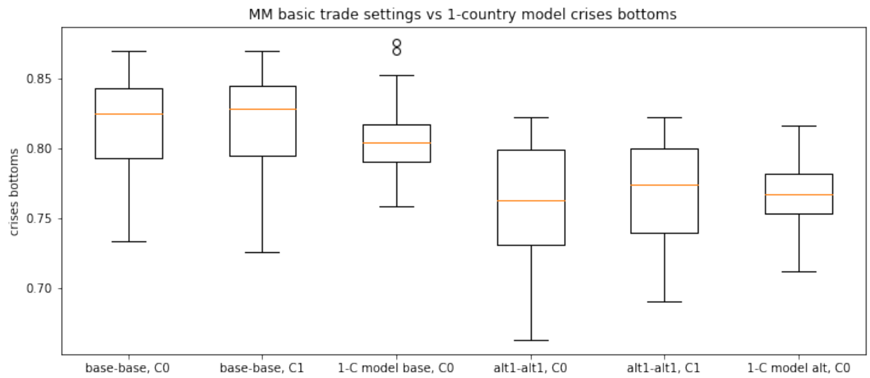
Figure 4.5: Comparison of the baseline scenarios in 2 and 1-country models, part 1



Note: On the left are data from a simulation of MM scenario with the baseline wage and trade settings in both countries. On the right are data from 1-country model with the baseline wage flexibility.

In the centre of our attention is to see how properties of economic crises change after the addition of international environment. Figure 4.6 illustrates distributions of the crisis bottoms across the baseline and the slightly flexible wage scenarios. We observe that while median bottoms in 2-country model in the baseline scenario are somewhat less deep, there is also considerably higher variability in the depth of crises when compared to 1 country model. In scenarios with more flexible wages we observe increase in variability of the crisis depths, while median values remain approximately the same. This is corroborated by descriptive statistics of the crisis measures for the mentioned scenarios, see table B.1. In addition, we see that occurrence of crises in 2-country models is on average somewhat higher relatively to the respective wage scenarios in 1-country model, while the lengths of crises are on the other hand shorter. Note that this is likely corollary of lower L-values and does not necessarily indicate quicker recovery. Statistical tests show that differences between mean crisis bottoms are, at 5% level, statistically significant for the baseline scenarios while those for L-values are statistically significant in each case (see table B.2).

Figure 4.6: Boxplots of crisis bottoms, 1-country and MM models



Note: Box-and-whiskers plots of crises bottoms in terms of employment rate across all simulations for given scenario and country. Included are the baseline and alternative scenarios for 1-country and MM 2-country models. For 2-country models, scenarios with identical wage settings in both countries are shown. C0 and C1 stands for the first and second country, respectively.

Table 4.3: Economic synchronization in MM model

variables	mean	min	median	max	std
base-base					
employment across	0.7279	0.5114	0.7353	0.9021	0.0708
BCsync metric	0.7784	0.5023	0.7921	0.9234	0.0799
alt1-alt1					
employment across	0.8567	0.7814	0.8552	0.9502	0.0354
BCsync metric	0.7901	0.4253	0.8097	0.9671	0.0929
base-alt1					
employment across	0.7389	0.5558	0.7413	0.9170	0.0660
BCsync metric	0.7345	0.3951	0.7463	0.9514	0.1003
base-alt2					
employment across	0.7840	0.3999	0.8042	0.9118	0.0828
BCsync metric	0.6894	0.4656	0.6879	0.9231	0.1020

Note: Data for the baseline trade settings. Employment across denotes correlation coefficients between employment rates of the two countries in a simulation. BCsync metric denotes data for the minimal rate of crises intersections.

Scenarios with the same wage flexibility in both countries

In figures 4.5 and B.4 we saw examples of some of the time series from a base-base simulation. First, we can notice that most of the time series are highly correlated. This is present across all wage scenarios. Table 4.3 statistically illustrates this on the case of employment rates and the metric of business cycles synchronization. This is despite the fact that exports represent only around 10% of sales for all of the countries in all four scenarios, see table B.3. In the case of the base-base scenario, both countries have the same design, thus it is expected that they will behave similarly during the times of relative stability. What is more interesting is their synchronization during the time of crises.

Generally, for the base-base scenario we can observe two types of crisis behaviour depending on whether crises in both countries start at approximately the same time or if crisis in one country precedes downturn in the other.

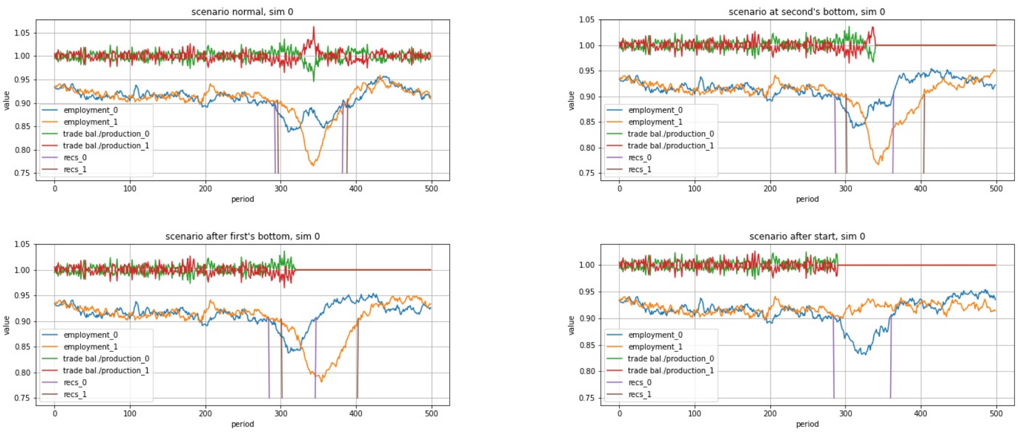
In the latter case (see upper left in the figure 4.7), we observe that while the first country enters a recession, it trade balances start to rise as firms try to offset their excessive supply by decreasing their prices, which increases their exports. Economy of the first country then starts to recover back towards the area of stability. However, increased imports from the first country cause shortage of demand for the domestic goods in the second country, which triggers recession. We see the same mechanism as before work in the reverse direction. Trade balances are turned around, recession in the second country reaches bottom while recovery in the first is reversed and the first economy starts to slow down again before it could even fully recover from the first downturn. But the negative thrust of the trade balances are not as long-lasting as during the first round of the mechanism proceedings, prices across the countries align, and both countries finally return back to the stability area at approximately the same time.

Figure 4.7 shows an experiment we performed in order to better illustrate these developments. In the upper left panel we see time series from the original simulation. On the upper right, we disabled trading between the countries just after the second country reaches the bottom of its recession. While the recovery of the first country have been already decelerated, it is able to continue after the influx of imports are stopped. This quickens return of the first country to the stability area while decelerate that of the second, relatively to the original simulation. In the lower left panel we show developments when international trade is prohibited at the best time for the first country's recovery, i.e. just after it reached its first crisis bottom and trade balances start to level off. In that case, first country is able to gain relatively quick recovery while the firms in the second country have no benefit of foreign market and the crisis is considerably prolonged in comparison to the original simulation. Finally, lower right panel shows situation when trading on foreign markets is prohibited just after the crisis in the first country began. Second country is then able to escape the crisis altogether, while the first country is left to recover solely on the basis of its domestic demand. The resulting crisis is deeper than in the original simulation, although return to the area of stability is in the end actually quicker.

If both countries enter recession at approximately the same time, the development of ensuing crises is more random. We observe that sometimes one of the countries is able to initialize recovery sooner and at higher levels of employment than the other. However, as this is followed by decreases in its trade balance, the other country is able to eventually catch up and both countries again fully recover at approximately the same time. Figure 4.8 provides illustration of both of these types of global crises.

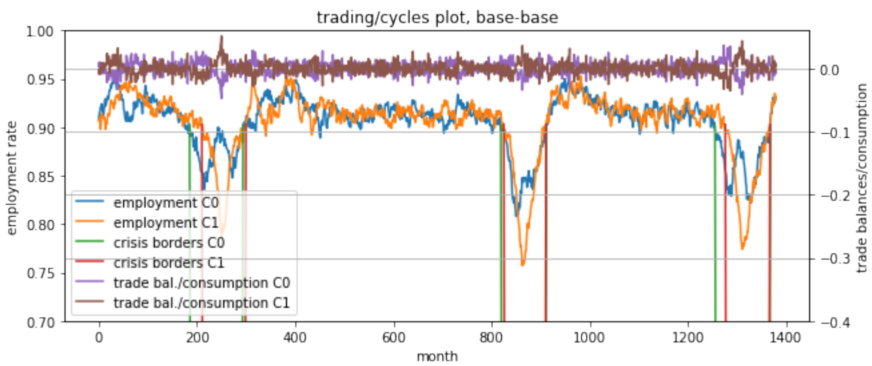
To show that whether country enters the recession first or second has ro-

Figure 4.7: Experiments with international trade prohibitions



Note: Upper left: original simulation.
Upper right: international trade prohibited just as the second country's recession bottoms.
Lower left: trade prohibited just after the first recession bottoms.
Lower right: trade prohibited just after the first recession started.
Real trade balance to domestic production ratios have been shifted upwards by 1 relative to the y-axis. Trade balance levels corresponding to 1 at the y-axis thus indicate periods when international trade did not occur. Data obtained from MM model with the baseline wage and (initially) trade settings.

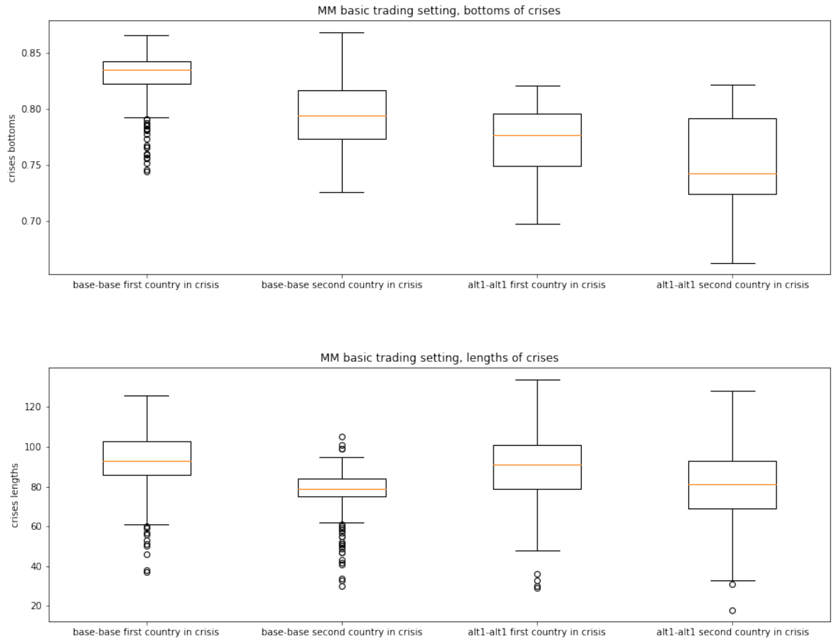
Figure 4.8: International trade and economic crises in MM model



Note: Second global crisis is a typical case when both countries enter the recession at approximately the same time. Trade balances are divided by real domestic consumption. Employment rate on the left y-axis, trade balance-consumption ratios on the right y-axis. Data obtained from MM scenario with the baseline wage and trade settings.

bust influence on the crisis severity, we offer figure 4.9 It displays distribution of crisis bottoms and lengths, respectively, with respect to which country enters the recession first. We see that in both wage scenarios, depths of the recessions of a country which enters sooner are concentrated around higher values, indicating less severe employment slumps. On the other hand, since crises in both countries usually end concurrently, the lengths of crises in the country which enters as second tend to be shorter.

Figure 4.9: Boxplots of crisis bottoms and lengths w.r.t. order of recession entrance, MM same wage scenarios

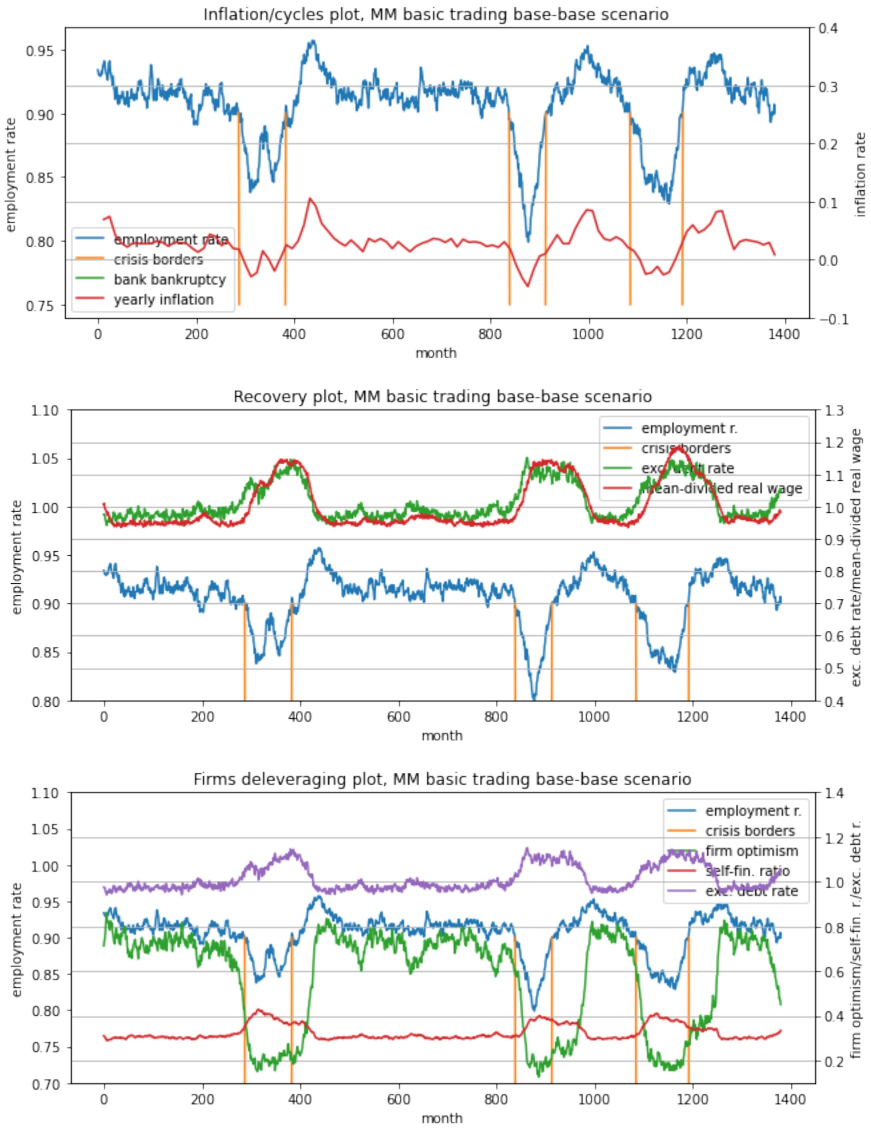


Note: First country in crisis stands for whichever country entered the recession during a global crisis sooner. Data across all global crises from MM scenarios with the baseline trade settings and identical wage settings in both countries.

As was the case with the 1-country model, the crises have debt-deflation characteristics. Figure 4.10 illustrates developments of inflation, real wages, firms excessive debt rates, their sentiments and self-financing ratios along the development of the employment rate. Similarly as in S-&-S, decrease in optimism of firms leads to decrease of their targeted levels of debt. This means that their excessive debt ratios (debts over targeted debts) increase and they decrease amount of dividends they pay out to their owners, which leads to decrease in households' income and aggregate demand. Fall in sales means increased inventories of firms which causes falls in prices and labour demand. Meanwhile, prices fall quicker than wages and thus real wages rise. The recession cycle is stopped when real wages reach high enough level such that sales of firms improve to the point when they decide to increase production. The recovery continues until an above-average levels of employment are reached. At that point, the economy is slightly overheated and firm prices rise quickly enough to return real wages and firm debts back to the stable levels.

Behaviour of the systems with medium levels of wage flexibility (alt1-alt1 scenario) can be characterized as broadly similar but more volatile then that of

Figure 4.10: Co-evolution of employment, inflation, real wages and firms' finances



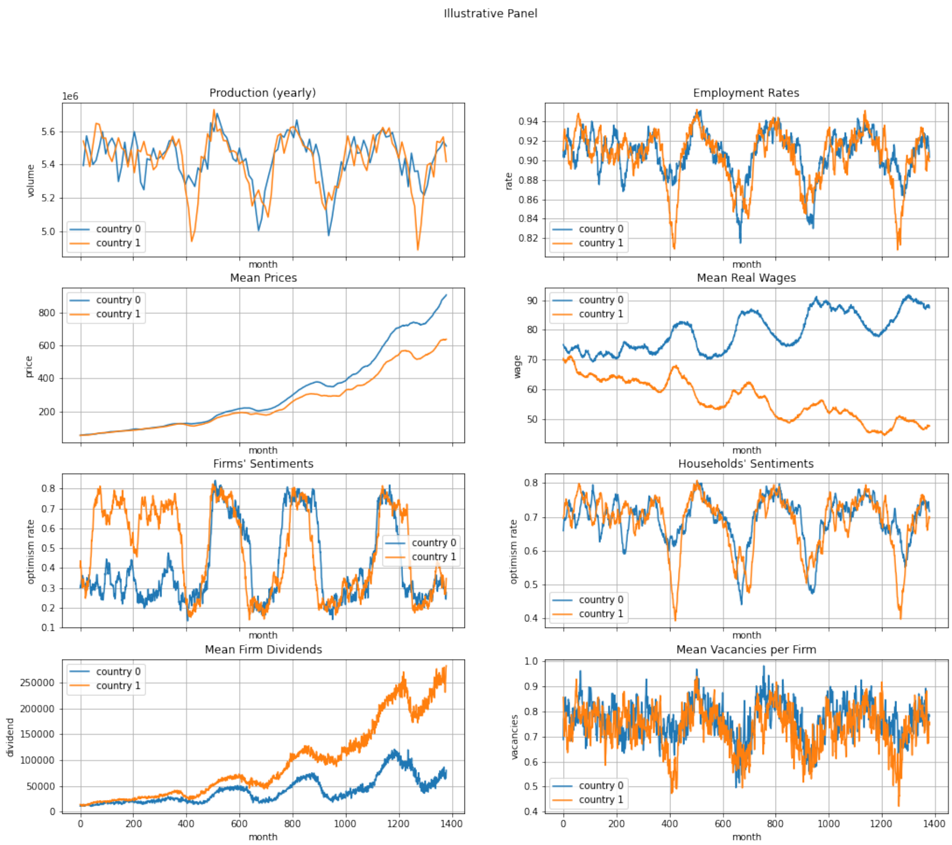
Note: Time series of employment and inflation rates, real wages, and firms' excessive debt, optimism and self-financing rates. Real wages in the second panel are divided by their average in order to standardize scale of plotted variables. Employment rate referenced on the left y-axis, other variables referenced on the right y-axis. Data example obtained from MM scenario with the baseline wage and trade settings.

base-base simulations. Crises are deeper (as we saw in figure 4.6), real wages and excessive debts of firms display greater variance and often higher peaks during the times of crises. Other real variables, such as inventories, sales, real dividends and others, also show greater variability. Greater instability of the system also leads to lower levels of inflation as sales of firms are more often too small to induce price increases and deflation is more severe in times of crises.

This indicates that more flexible wages have destabilizing effects in our MM model. See below for more elaborate comparisons.

Scenarios with mixed wage flexibilities

Figure 4.11: Illustration of macroeconomic developments in MM base-alt1 scenario with baseline trade settings



Note: Yearly production time series is linearly interpolated over monthly x-axis.

Figure 4.11 provides illustration of a base-alt1 simulation. We observe that, due to different levels of inflation, nominal variables of the two countries diverge. So do real wages. In table 4.4 we see that country 0, which has baseline wage flexibility, has somewhat higher levels of production, sales, and consumption. Meanwhile, firms in country 1 with more flexible wages have higher levels of inventories. There are significant and, as can be seen from the figure 4.11 , over time increasing differences in real wages and profits. We have seen that, in scenarios where both countries have the same wage flexibility, both countries settle in very similar areas of stability. However, in the present case there are unequal pressures on wages as households in the country 1 are more willing to accept smaller wages than those in country 0. Smaller wages lead to lower aggregate demand and sales of firms. This affects prices as firms with excessive inventories are not willing to increase them. Consequently, firms in country 1 are able to sell their goods for slightly smaller prices than their counterparts in the country 0. Due smaller wages they to do so with profit. This enables them to export higher proportions of their goods (see table B.3) and thus compensate for the lost demand at home (though, as can be seen from higher levels of inventories for firms in country 1, this compensation is not complete). As a result, a stable trend of increasing profits and decreasing wages in the country 1 (and vice versa in the country 0) is sustained.

In the case of the base-alt2 scenario, these effects are even stronger, as summarized in table 4.4.

Similarly as was the case with the same-wage scenarios, we can observe that, with regard to which country enters a recession during global crisis as first, countries that enter recessions sooner have less deep bottoms and are somewhat longer in the crises (see figure B.5).

If in addition we break down these effects with respect to countries 0 and 1 (see figure 4.12), we observe that there are substantive differences in distributions of crisis bottoms depending on whether the first country in crisis is country 0 or country 1. In the former case, the second country goes through notably deeper crisis than the first one. On the other hand, if the crisis starts in the country with more flexible wages, then we see that both countries have comparable distributions of crises depths, which are also similar to that of country 0 in the former case. Crises are in that instance markedly milder and country 1 is able to recover due to increased exports without dragging down the economy of its trading partner into a deep recession.

Comparison of the four scenarios

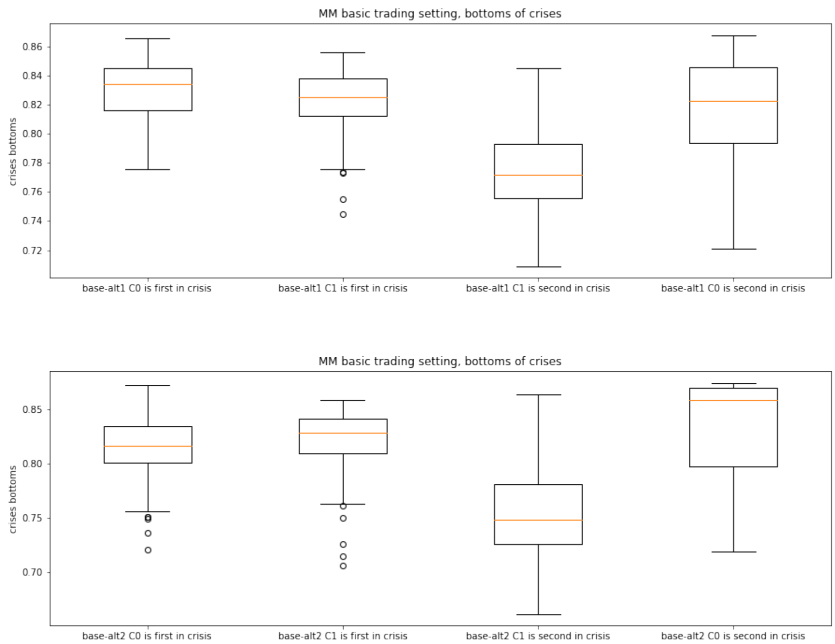
Finally, we compare crises in all of the four wage flexibility scenarios. To start, figure 4.13 offers visual representation of crises bottoms' distributions and table 4.5 presents descriptive statistics of crisis depths and L-values (stability are lower borders). Countries in alt1-alt1 scenario experience crises which are robustly more severe than those of countries in the base-base scenario. We can observe that crises depths across countries with the baseline wages do not

Table 4.4: Descriptive statistics of averages of monthly macroeconomic time series, MM mixed wage and baseline trading scenarios

	min	mean	max	std	mean inner std	std of inner std
base-alt1						
production C0	817.3	823.3	828.1	1.9276	42.30	2.31
production C1	813.2	820.3	826.6	2.2500	45.03	2.45
sales C0	817.2	823.2	827.9	1.9294	23.53	3.10
sales C1	813.2	820.2	826.4	2.2500	27.43	3.32
consumption C0	90.1	90.7	91.3	0.2148	2.50	0.3850
consumption C1	89.2	90.0	90.7	0.2654	3.14	0.4115
inventories C0	1681.1	1698.6	1720.1	6.99	156.16	16.46
inventories C1	1706.8	1728.4	1747.7	7.88	182.22	17.94
real profits C0	169.8	189.6	215.7	9.85	57.06	4.68
real profits C1	361.3	382.0	400.3	7.61	65.02	6.48
real wages C0	74.9	77.9	80.2	1.1799	6.80	0.5647
real wages C1	51.6	53.9	56.5	0.9625	7.37	0.6717
base-alt2						
production C0	821.8	824.6	828.0	1.3093	40.7	2.02
production C1	807.0	816.7	826.3	3.3600	47.4	4.30
sales C0	821.6	824.6	828.1	1.3068	21.32	3.14
sales C1	806.9	816.5	826.3	3.3800	31.51	6.15
consumption C0	90.7	91.1	91.4	0.1501	2.09	0.3826
consumption C1	88.0	89.3	90.6	0.4495	3.76	0.8282
inventories C0	1684.4	1697.8	1709.6	5.63	118.71	10.26
inventories C1	1728.1	1760.3	1785.6	10.67	169.71	13.88
real profits C0	64.2	97.9	142.7	16.73	62.25	7.54
real profits C1	470.2	553.8	655.0	39.22	120.99	9.56
real wages C0	83.8	89.2	93.2	2.03	7.76	0.8610
real wages C1	19.1	32.4	43.4	5.07	13.64	0.9042

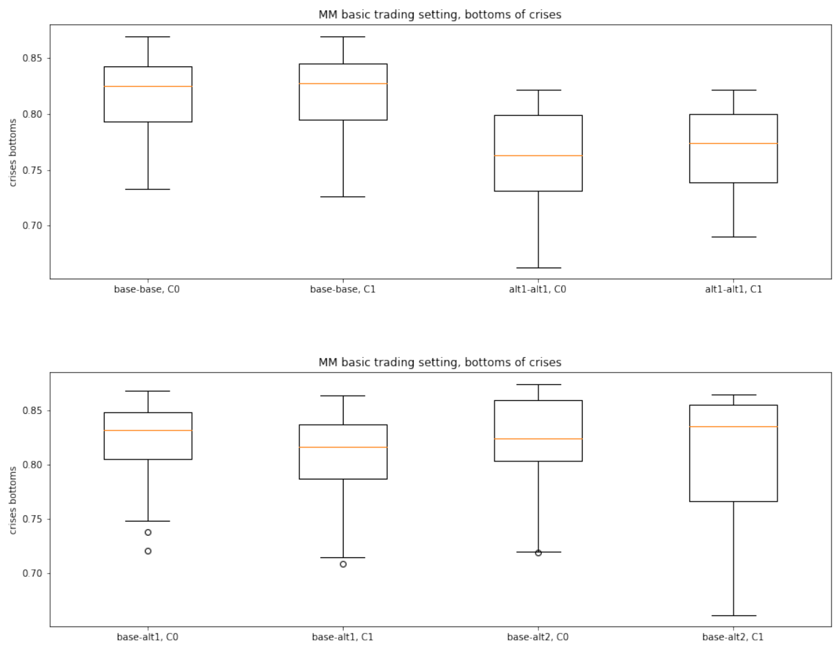
Note: Reported values indicate real terms. Columns 2-5 report descriptive statistics of datasets in which individual data points represent averages of respective time series per simulation. Columns 6 and 7 display means and standard deviations of datasets in which individual data points represent standard deviations of respective time series per simulation.

Figure 4.12: Boxplots of crisis bottoms w.r.t. order of entrance into crisis and wage flexibility, MM mixed wage scenarios



Note: Country X first in crisis stands for country X's data from global crises in which country X entered the recession before the other country. Data across all global crises from MM scenarios with the baseline trade and mixed wage settings.

Figure 4.13: Boxplots of crisis bottoms, MM basic trading scenarios



dramatically differ across different scenarios. On the other hand, if we compare crises of the alt1-alt1 scenario, where both countries have moderate levels of wage flexibility, with those of the base-atl1 scenario, we see large difference. Mixing a country with moderate wage flexibility with one with the baseline wage flexibility leads to considerable reduction in average crisis depths in the former – by around 4 percentage points. There is also slightly less variability in the crisis bottoms, although we see that, occasionally, the deepest recessions can still reach levels of 29% unemployment rate.

Mixing country with extremely flexible wages with the baseline wage country leads to similar results in terms of average bottoms, although they are significantly more volatile and reach more extreme minima. This is quite remarkable given that in the 1-country models with very flexible wagesany recession leads to unemployment rates of more than 50% and breakdown of the economic realism of the model.

Lastly, we execute formal testing of equality of mean crisis bottoms across simulated countries (see table B.5). The results show there are statistically significant differences between the measures across most of the countries. Apart from countries which are by design equivalent (pairs of countries in the same wage scenarios,) we fail to reject equality of means at 5% level of confidence only if we compare countries with the baseline wage flexibilities in the base-base scenario with that in the base-alt2 scenario, and when we compare countries 1 from the base-alt1 and the base-alt2 scenarios. The former suggest that increasing wage flexibility of its trading partner does not significantly influence resistance against recessions of the baseline wage flexibility country. The latter, on the other hand, suggests that trading with country with the baseline wages leads to very similar crises developments, regardless of whether the country in question has only moderately flexible wages or very flexible ones. Countries with flexible wages are able to rescue themselves from economic collapse by trading with a stable-wage partner.

Table 4.5: MM baseline trade scenarios, descriptive statistics of crisis measures

	mean	min	median	max	std
base-base					
L-value C0	90.02	88.5	90.2	90.8	0.4900
L-value C1	90.00	88.5	90.1	90.8	0.5000
bottoms C0	81.75	73.3	82.5	87.0	3.3000
bottoms C1	81.87	72.6	82.8	87.0	3.3100
alt1-alt1					
L-value C0	85.21	82.2	85.2	88.3	1.1900
L-value C1	85.22	82.2	85.2	88.8	1.1700
bottoms C0	76.41	66.3	76.3	82.2	3.6900
bottoms C1	76.98	69.0	77.4	82.2	3.4900
base-alt1					
L-value C0	89.87	88.6	89.9	90.8	0.3800
L-value C1	89.39	87.8	89.4	90.3	0.5000
bottoms C0	82.52	72.1	83.2	86.8	3.0100
bottoms C1	80.95	70.9	81.6	86.3	3.3700
base-alt2					
L-value C0	90.4200	89.80	90.4	90.9	0.2000
L-value C1	89.4500	88.68	89.4	90.2	0.3100
bottoms C0	82.2800	71.90	82.4	87.4	3.9400
bottoms C1	81.1800	66.20	83.5	86.4	5.2800

Note: Descriptive statistics for crisis measures across given wage flexibility setting and country, in per cents. Bottoms refer to crises bottoms. L-value refers to the estimates of lower border of the employment rate stability area.

4.3.2 Robustness check w.r.t different trade settings

Monetary Union

When exchange rates are pegged there is no feedback in prices to trade balances, hence we observe higher fluctuations in trade balances during crises. Response in employment is in consequence also stronger. In the base-base scenario, in the case of recessions which one country enters sooner than the other, first country does no longer show robustly less severe crises as feedback effects from the second country are stronger and often lead to second bottom of the first country to be deeper than the first one. In some cases, it becomes even deeper than that of the second country. Overall, differences between the first and the second country in global crises are thus muted.

Next, we observe that in mixed wage scenarios crises in the country with more flexible wages is even milder than in the case of floating exchange rates. In the case of the base-alt2 scenario it seems that country 1 has actually less deep bottoms than the baseline wage country. Eliminating balancing effects of exchange rates on international trade leads to higher ability of the flexible wage country to benefit from exports, especially when it experiences crisis.

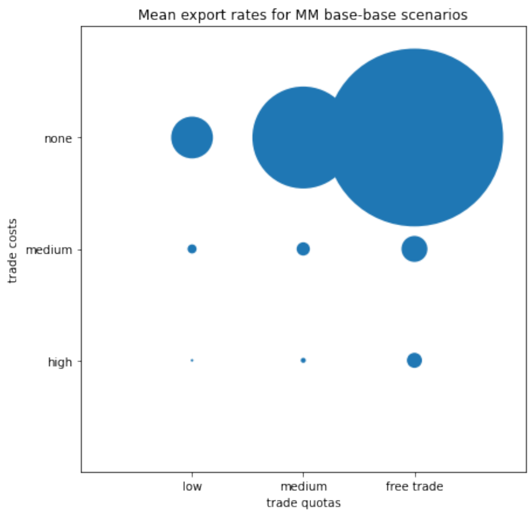
Otherwise, similar general conclusions as in the basic trading settings on how less flexible wages help to smooth recessions still hold.

Changing trade costs and quotas

Figure 4.14 visualizes effects of different trade settings on export rates of the country 0 in the base-base wage scenarios. When trade costs are high and quotas are low we observe, on average, almost no international trade. On the other end of the spectrum is the case of free trade with no costs or quota restrictions. In such instances the only characteristics distinguishing countries from each other are separation of their labour markets and different wage flexibilities (for mixed wage scenarios). For same wage scenarios, there are no significant deflections of trade balances to either side, hence exchange rates oscillate close to parity. Export rates are thus around 50%, as there is nothing which induces consumers to prefer domestic goods over the foreign ones in any robust manner. If one of the country has more flexible wages, it still on average gains somewhat positive trade balances, but the export rates in both countries are close to 50%.

Figure 4.15 visualizes synchronizations of economies in the base-base wage scenarios under different trade settings. We see very high levels of synchronization for zero trade costs scenarios even with very restrictive quotas levels. In other cases, both higher trade costs and lower quotas lead to less synchronization.

Figure 4.14: MM mean export rates

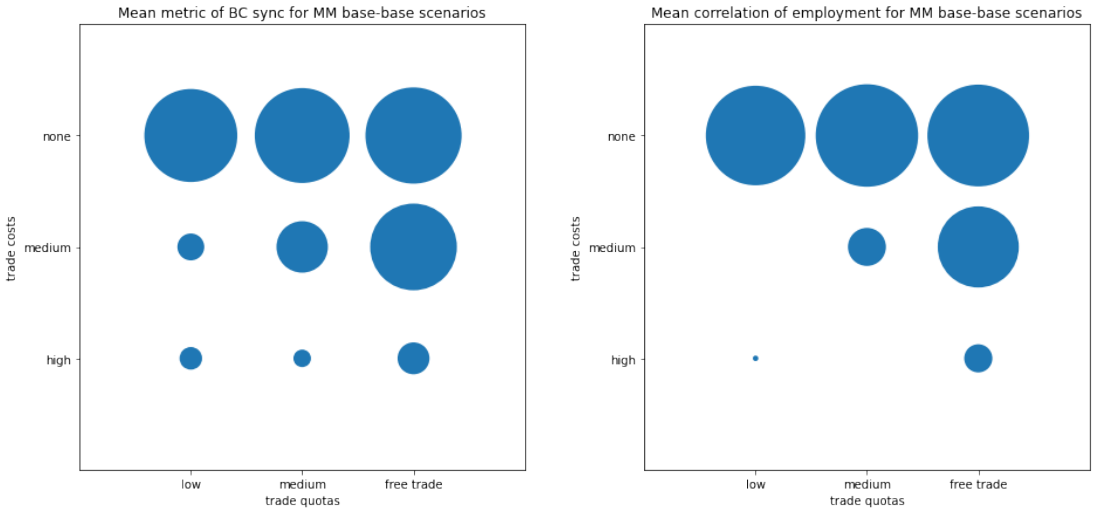


Note: Area of a circle is equal to the average of the mean export rates of the country 0 across simulations from the scenario with the baseline wage and given trade settings. Distance between centres of neighbouring circles is 1. Baseline trade settings are no binding quotas, i.e. free trade, and medium costs.

Regarding impact of wage flexibilities on economic stability in the presence of international trade, basic lessons learnt from the baseline trade scenarios still hold for countries with at least/most medium levels of trade quotas/costs, respectively. Even in the case of high trade costs and low quotas, where there is almost no international trade, we observe that countries with highly flexible wages do not experience as strong economic collapse during recessions as was the case with 1-country models.

For the sake of illustration at extremes, figure 4.16 compares distributions of crisis bottoms across base-base and alt1-alt1 scenarios vis-à-vis 1-country baseline and moderate alternative scenarios for both trade settings with high costs and low quotas and with no costs nor quota restrictions. In the former cases, due to high trade restrictions, the simulated systems approach those of two separate 1-country simulations. In the latter case, only separation of labour markets and ownership of banks and firms make countries distinct from one large country in terms of their design. Yet we still observe that, while shapes of distributions are similar across all cases, they are shifted somewhat upwards in 2-country models in comparison to 1-country models, especially for high-trading settings. This suggest positive impact of international trade on severity of recessions. In the first case, this happens in the context of no

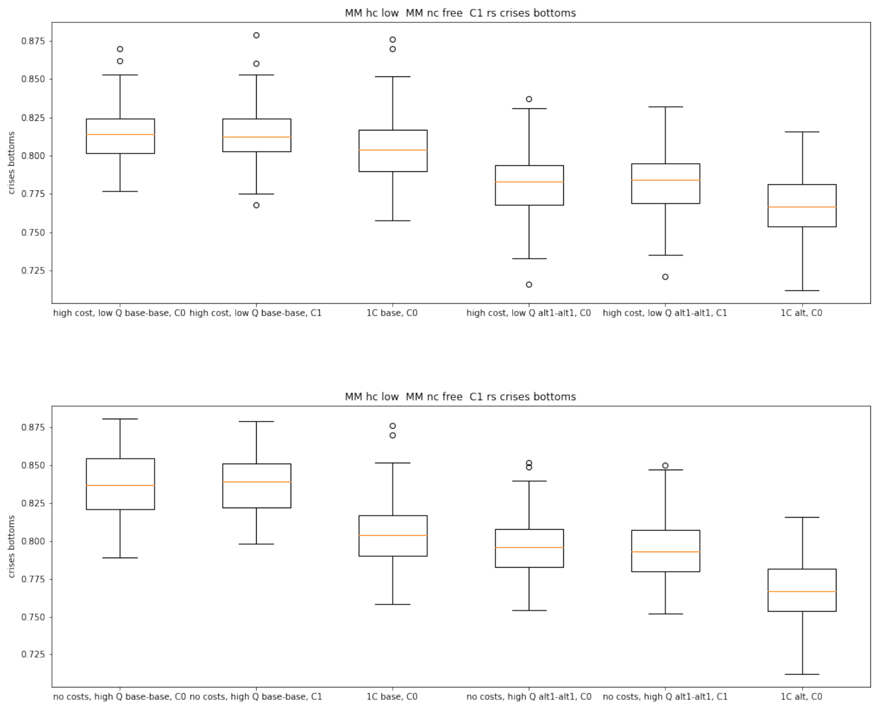
Figure 4.15: MM business cycles synchronizations



Note: Diameter of a circle is equal to the average of metric of BC synchronization (left figure) or to the average of mean employment cross-correlation (right figure) across simulations from the baseline wage scenario with the given trade settings. Distance between centres of neighbouring circles is 1. Baseline trade settings are no binding quotas, i.e. free trade, and medium costs. Negative average correlations are represented as circles with 0 diameter.

distinct business cycle synchronization, in the latter in the context of highly synchronized business cycles.

Figure 4.16: Boxplots of crisis bottoms, 1-country models and MM scenarios with very low and very high levels of trading



Note: Upper panel: MM same wage scenarios with highly restricted international trade (high trade costs and low trade quotas) are compared to 1-country baseline and alternative scenarios.
Lower panel: MM same wage scenarios with no restrictions on international trade (zero trade costs and no quota restrictions) are compared to 1-country baseline and alternative scenarios. 1C denotes 1-country model, base and alt1 are wage flexibility settings labels, C0 and C1 denote the first and the second country, respectively. Q denotes trade quotas.

4.4 Models with one large and one small country

Similarly as in the section concerning MM models, we begin by discussing scenarios with the baseline trading settings and continue with the examination of impacts of monetary union and different trade costs and tariffs. We again vary wage flexibility between the same three levels, but as the countries have different size, we additionally differentiate between scenarios where the large country has the baseline wage flexibility while the small one has more flexible wages (base–alt1, base–alt2), and those where these settings are reversed (alt1–base, alt2–base). Together with settings where both countries have either baseline (base–base) or moderately flexible wages (alt1–alt1) this gives us six different wage flexibility scenarios for each trading setting. Note that we denote the large country as the first country or country 0 and the small country as the second country or country 1.

4.4.1 Basic trade settings

In the case when one of the country is significantly larger than the other (the ratio is 4 : 1), we observe that the economy of the small country is considerably more volatile. The recessions of the large country have strong effects on the small country, which usually suffers deeper crises bottoms. On the other hand, downturns in the small country rarely erupt into the full recessions without the contagion from abroad as firms in small countries are quickly able to satisfactorily correct for lack of domestic demand by exporting abroad. The basic relations of the wage scenarios and recession severity are broadly in line with analogous scenarios with the same sized countries.

Scenarios with the same wage flexibilities in both countries

Figure 4.17 illustrates a base-base scenario simulation. Similarly as we saw in the previous section, the two economies are highly synchronized. For example, average correlation coefficient for employment rates is 82% and metric of business cycles synchronization shows average values of 77%. For alt1-alt1 scenario these values are even higher by about 10 percentage points (see table B.6).

We also observe that level of employment in the small country during the stability periods is lower and more volatile than in the large. Table 4.6 presents descriptive statistics for average employment rates during the non-crisis periods. In all six wage scenarios, area of stability employment rates of the large

Figure 4.17: Illustration of macroeconomic developments in LS base-base scenario with the baseline trade settings

Note: Yearly production time series is linearly interpolated over monthly x-axis.

country are higher by at least 2 percentage points while their average standard deviation in same wage scenarios is approximately 5 percentage points lower than in the small country.

Meanwhile, firms in the small country are considerably more dependent on exports. Export rates are stably moving around 10% for the small country and 2% for the large (see table B.7). Consequently, small country has trading surpluses (see table 4.7), its currency becomes more valuable and it experiences lower levels of inflation. The latter follows from the fact that higher prices would tarnish export opportunities. We also observe different income distributions across the two countries. The real wage in the small country is for same wage scenarios approximately 10 units higher than in the large one. This difference is roughly constant throughout the length of individual simulations.

Table 4.6: LS baseline trade scenarios, descriptive statistics of employment rates during non-crisis periods

	min	mean	max	std	mean inner std	std of inner std
base-base						
country 0	0.9185	0.9232	0.9272	0.0018	0.0105	0.0029
country 1	0.8913	0.8971	0.9024	0.0020	0.0161	0.0020
alt1-alt1						
country 0	0.9078	0.9172	0.9213	0.0027	0.0176	0.0055
country 1	0.8817	0.8908	0.8968	0.0029	0.0224	0.0043
base-alt1						
country 0	0.9175	0.9231	0.9274	0.0016	0.0109	0.0022
country 1	0.8922	0.8989	0.9038	0.0022	0.0175	0.0021
alt1-base						
country 0	0.9144	0.9208	0.9254	0.002	0.0169	0.0041
country 1	0.8886	0.8936	0.8982	0.002	0.0200	0.0024
base-alt2						
country 0	0.9193	0.9224	0.9258	0.0013	0.0095	0.0017
country 1	0.8944	0.8995	0.9040	0.0017	0.0157	0.0016
alt2-base						
country 0	0.9017	0.9086	0.9177	0.004	0.0133	0.0022
country 1	0.8520	0.8620	0.8772	0.006	0.0292	0.0021

Note: Reported values are based on data when given economy was not in crisis. Columns 2-5 report descriptive statistics of datasets in which individual data points represent averages of stability area-employment rates per simulation. Columns 6 and 7 display means and standard deviations of datasets in which individual data points represent standard deviations of stability area-employment rates per simulation.

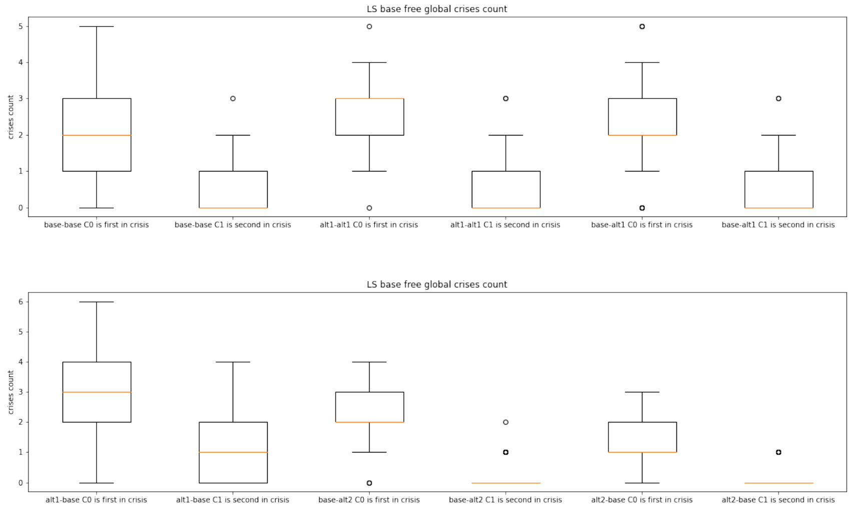
Table 4.7: LS baseline trade settings, descriptive statistics of yearly real trade balances

	min	mean	max	std	mean inner std	std of inner std
base-base						
country 0	-37810.8	-35991.1	-33944.0	782.77	25623.6	2509.01
country 1	33944.0	35991.1	37810.8	782.77	25623.6	2509.01
alt1-alt1						
country 0	-37902.9	-35237.1	-32341.2	1082.46	27805.03	1935.39
country 1	32341.2	35237.1	37902.9	1082.46	27805.03	1935.39
base-alt1						
country 0	-47784.9	-45678.0	-44062.4	805.75	27700.57	2247.36
country 1	44062.4	45678.0	47784.9	805.75	27700.57	2247.36
alt1-base						
country 0	-24462.1	-16724.3	-11199.0	2535.05	54423.2	8305.02
country 1	11199.0	16724.3	24462.1	2535.05	54423.2	8305.02
base-alt2						
country 0	-56868.3	-54041.9	-51691.2	1148.66	25566.09	2283.99
country 1	51691.2	54041.9	56868.3	1148.66	25566.09	2283.99
alt2-base						
country 0	-8019.5	3803.2	12841.5	5920.04	54147.06	4611.9
country 1	-12841.5	-3803.2	8019.5	5920.04	54147.06	4611.9

Note: Columns 2-5 report descriptive statistics of datasets in which individual data points represent averages of yearly real trade balances per simulation. Columns 6 and 7 display means and standard deviations of datasets in which individual data points represent standard deviations of yearly real trade balances per simulation.

Such relations between variables of the small and large countries are established during the burning-in periods. At first, due to their numeric advantage, firms from the large country are able to sell their products on the small country's market in relatively high numbers and trade balances are in favour of the large country. This creates pressure on firms from the small country to keep their prices down. Consequently, as firms in the small country face strong pressures from the large foreign competition while firms in the large country are able to develop in an environment more similar to a closed economy, different stability levels of employment, production, sales and real wages are established across the two countries.

Figure 4.18: Boxplots of crisis counts w.r.t. order of recession entrance, LS baseline trading scenarios



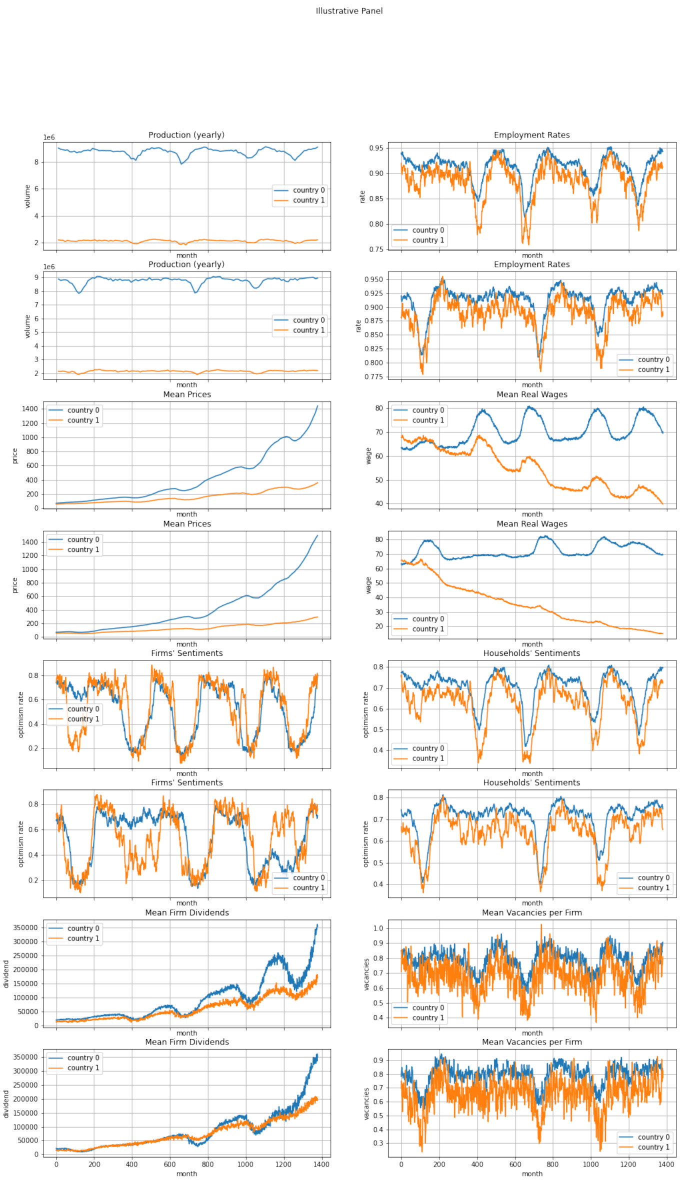
Note: Y-axis indicates number of crises per simulation. First country in crisis stands for whichever country entered the recession during a global crisis sooner. Data across all global crises from LS scenarios with the baseline trade settings.

Regarding recessions, we observe that the small country rarely enters a global recession as first (see figure 4.18). Large majority of global crises are initiated from the large country, when influx of cheapened imports drags sales of small country's firms down. On the other hand, there are many instances of small drops in small country's employment rates which do not erupt into full crisis as evidenced by total time spend in crises, especially for base-base scenario (see table B.8). The average value is 184.5, far below the expected value of 345, the quarter of our simulation lengths (see the Appendix A for discussion of crisis length interpretation). Even if such drops are qualified as recessions, small country is usually able to recover without inducing crisis in the large country.

Scenarios where the small country has more flexible wages

In figure 4.19 we see examples of macroeconomic time series for scenarios base-alt1 and base-alt2. Economies are still highly correlated, although somewhat less as the wage flexibility differences grow (see table B.6). Effects of different country sizes described in the previous part and effects of different wage flexibilities described in the section about MM base-alt1, base-alt2 settings are both at play here. This results in the small country, which has more flexible wages, having even higher export rates and trade surpluses than in the case of

Figure 4.19: Illustration of macroeconomic developments in LS base-alt1 and base-alt2 scenarios with the baseline trade settings



Note: Yearly production time series is linearly interpolated over monthly x-axis. In each pair of rows, data from base-alt1 scenario are in the upper row, those from the base-alt2 scenario are in the lower row.

the same wage scenarios (see tables B.7, 4.7). Currency of the small country is even stronger and differences in inflation and nominal variables of the two countries are larger. Meanwhile, higher flexibility of wages in one country once again results in real wages decreasing and real profits and dividends of firms of that country increasing over time. In both scenarios it holds that the small country rarely enters a global recession as first.

Scenarios where the large country has more flexible wages

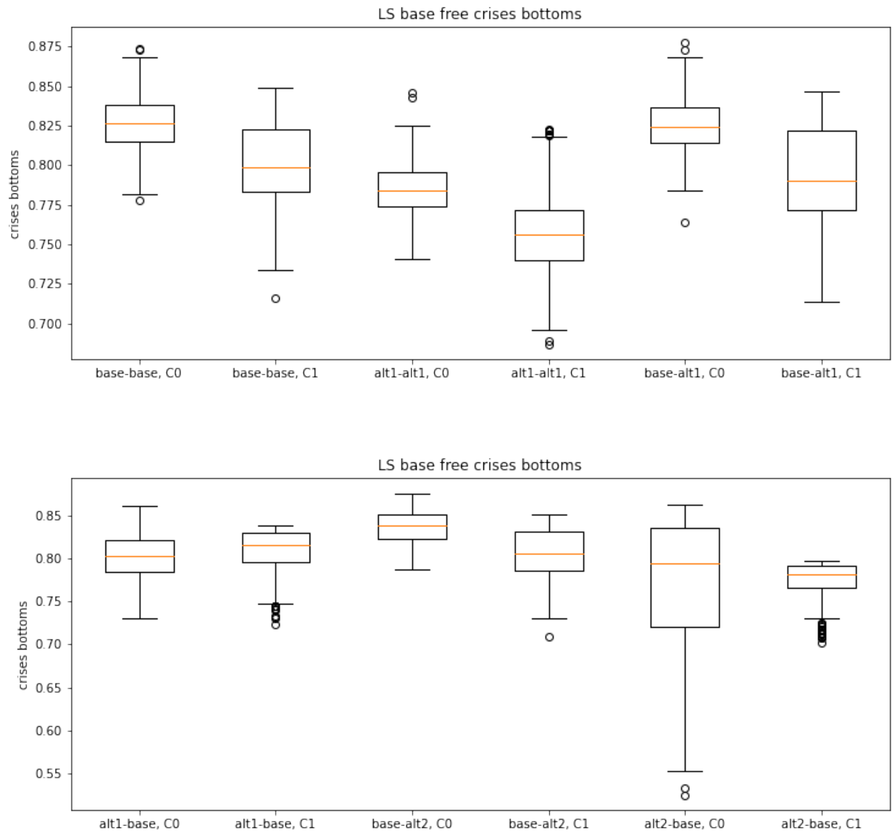
In scenarios alt1-base and alt2-base, large economies have flexible wages. Previously discussed effects of discrepancies in wage flexibility and country size on international trade work against each other. Differences in export rates of the two countries are lower than in the previous four scenarios (see table B.7). The large country has, on average, positive trade balances in the alt2-base scenario (see table 4.7). In both scenarios, trade balances are also on average approximately twice as volatile as in the previous four scenarios. We observe that inflation rates are still lower in the small country while real wages have negative trend in the large country. Situation of firms in the small country is dire, especially in the more extreme alt2-base scenario. Due to lower wage flexibility their profits are decreasing, they cannot compete with firms from the large country as effectively as in the previous scenarios. There are relatively many bankruptcies and they can scarcely afford to pay out any dividends. The employment rates in the small country in alt2-base scenario are generally significantly lower as can be also seen from its L-value (see table 4.8). It is only 0.827, whereas in other scenarios it is no lower than 0.85. See figure B.6 for illustrative examples of time series from the alt1-base and alt2-base scenarios.

Comparison of the six scenarios

Figure 4.20 depicts distributions of crisis bottoms across the six scenarios while table 4.8 presents summary statistics of crisis measures. Crises in countries with more flexible wages are always deeper on average. In the same-wage scenarios, the large country has less severe crises and this is reflected in mixed wage scenarios as well – if the country with more flexible wages is large than the difference between the severity of crises between the two trading partners with different wage flexibilities are much smaller.

Also, in almost all cases we see that if countries trade with a partner with the baseline wage flexibility, the severity of crises are smaller than in corresponding alt1-alt1 case. Exception is alt2-base scenario, where extreme wage flexibility in the large country leads to relatively very deep crisis in both countries. Moreover, average crisis bottoms in the large country are approximately

Figure 4.20: Boxplots of crisis bottoms, LS scenarios with the baseline trade settings



Note: Notice the differences in the ranges of y-axis.

four times as volatile as in other scenarios, with maximal unemployment of 47.5% reached. This is also considerably worse than in the corresponding MM base-alt2 scenario, showing that trading with a small stable-wage partner is unable to mitigate depressions as effectively as trading with a same-sized one. However, these outcomes are still a considerable improvement upon scenario with extremely flexible wages in the 1-country model as we do not observe such complete economic breakdown as in the latter case. Hence, we can conclude that in our simulated economies, international trade even with a small country with stable wages significantly improves stability of the simulated economy.

Next, we observe that if the large country has the baseline wage flexibility there are relatively small changes in the harshness of its crises. On the other hand, severity of crises in the small country are much more dependent on the wage flexibility in the large country. For example, differences between mean crises bottoms of the large country in scenarios base-base and base-alt1 are not even statistically significant (see table B.9).

Also note that average total time spend in crises is for the small country always significantly lower than 345, suggesting high levels of small downward deviations from the stability area.

4.4.2 Robustness check w.r.t. different trade settings

Changing trade costs and quotas

Figure 4.21 visualizes effects of different trade settings on export rates of both large and small country in the base-base wage scenarios. When trade costs are high and quotas are low we observe on average only very small levels of international trade, with exports comprising less than 0.1% of sales on average in the small country. On the other hand, free trade with no costs or quota restrictions leads to average export rates around 80% in the small and 20% in the large country. This is corresponding to their relative size ratio of 1 : 4.

Figure 4.22 visualizes synchronizations of economies in the base-base wage scenarios under different trade settings. Similarly as with MM scenarios, we observe very high levels of synchronization for no trade costs scenarios regardless of quotas levels. In other cases both higher trade costs and lower quotas lead to less synchronization.

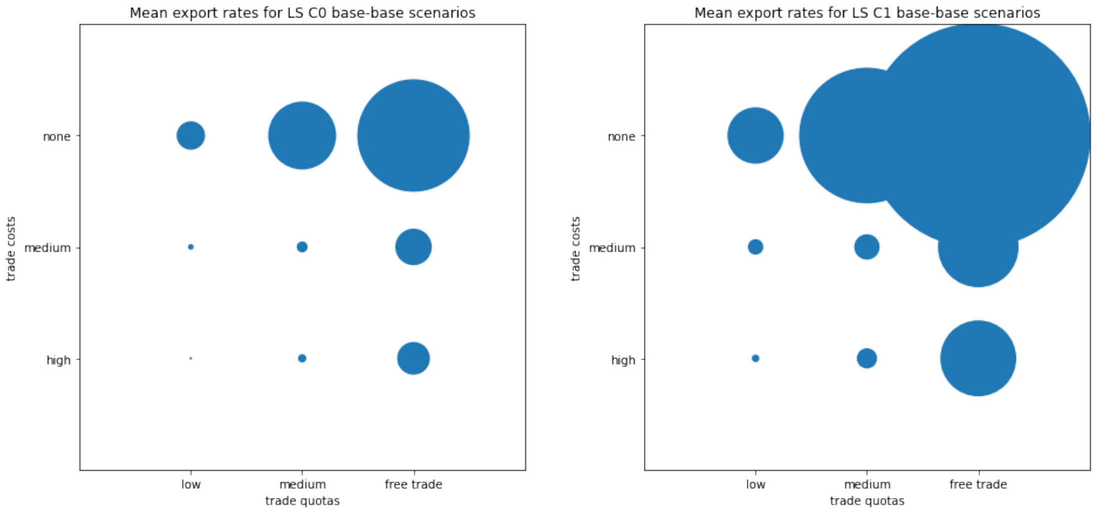
Even under highly restricted trade, in the case of a deep recession trade balances are able to increase to highs sufficient for lifting the sales of firms enough to stop the downward spiral. This is evident especially in base-alt2 and

Table 4.8: LS baseline trade settings, descriptive statistics of crises measures

	mean	min	median	max	std
base-base					
L-value C0	91.20	89.58	91.20	91.7	0.3800
L-value C1	87.96	87.00	88.00	88.7	0.3900
bottoms C0	82.69	77.80	82.65	87.4	1.7100
bottoms C1	80.22	71.60	79.90	84.9	2.8000
alt1-alt1					
L-value C0	87.90	84.3	88.3	90.4	1.6200
L-value C1	85.39	82.8	85.6	87.2	1.0900
bottoms C0	78.50	74.1	78.4	84.6	1.6800
bottoms C1	75.72	68.7	75.6	82.3	2.6600
base-alt1					
L-value C0	90.93	89.1	91.0	91.6	0.4800
L-value C1	87.72	85.9	87.8	88.8	0.5400
bottoms C0	82.61	76.4	82.4	87.8	1.7300
bottoms C1	79.51	71.4	79.0	84.7	3.1700
alt1-base					
L-value C0	89.23	87.28	89.0	91.3	0.9400
L-value C1	86.87	85.78	86.9	88.1	0.5300
bottoms C0	80.30	73.10	80.3	86.1	2.6800
bottoms C1	80.99	72.40	81.6	83.8	2.4900
base-alt2					
L-value C0	91.18	90.5	91.20	91.7	0.2800
L-value C1	88.19	87.0	88.20	89.0	0.3700
bottoms C0	83.65	78.7	83.90	87.6	1.9400
bottoms C1	80.67	70.9	80.55	85.1	2.9000
alt2-base					
L-value C0	89.21	88.3	89.2	89.9	0.3100
L-value C1	82.74	81.4	82.4	85.3	1.0200
bottoms C0	76.76	52.5	79.4	86.2	8.5200
bottoms C1	77.60	70.2	78.2	79.7	1.9700

Note: Descriptive statistics for crisis measures across given wage flexibility setting and country, in per cents. Bottoms refer to crises bottoms. L-value refers to the estimates of lower border of the employment rate stability area.

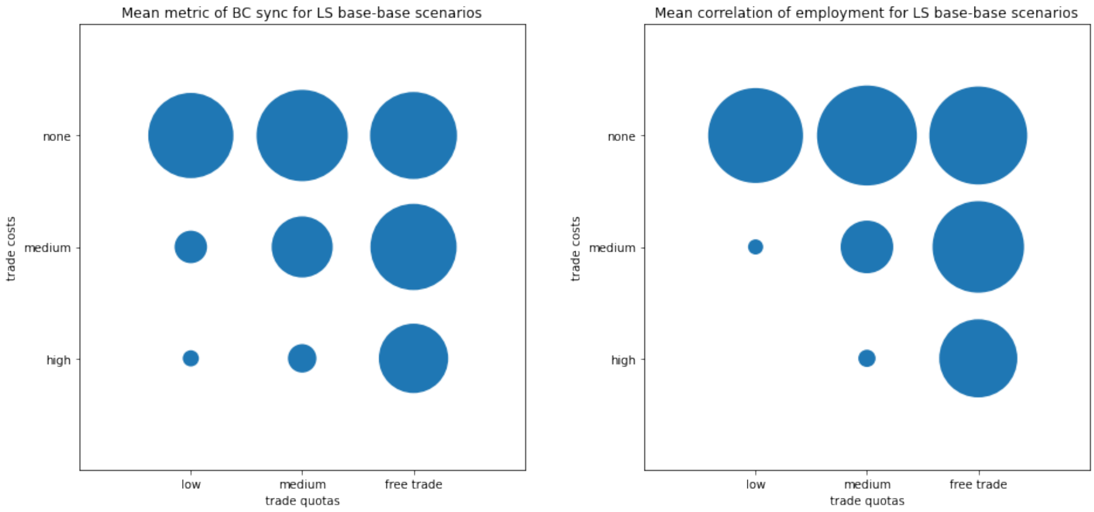
Figure 4.21: LS mean export rates



Note: Area of a circle is equal to the average of the mean export rates of the large (left figure) or small (right figure) country across simulations in the base-base wage scenario with the given trade settings. Distance between centres of neighbouring circles is 1. Baseline trade settings are medium costs and no quotas restrictions (denoted as free trade).

alt2-base wage scenarios, where the economy with extremely flexible wages does not collapse as in the 1-country models but is able to recover without its bank going bankrupt.

Figure 4.22: LS business cycles synchronizations



Note: Diameter of a circle is equal to the average of metric of BC synchronization (left figure) or to the average of mean employment cross-correlation (right figure) across simulations in the base-base wage scenario with the given trade settings. Distance between centres of neighbouring circles is 1. Baseline trade settings are medium costs and no quotas restrictions (denoted as free trade). Negative average correlations are represented as circles with 0 diameter.

4.5 Discussions and future developments

Here, we first compare our model with Gali (2013) and Gali & Monacelli (2016) as representatives of the recent literature on wage flexibility impact.

In comparison to them, we consider indebtness of firms and debt-deflation crises (not only deflation), which is an important addition. Our use of constant nominal interest rates is to an extent analogous to a situation of binding zero-lower bound or inelasticity of common interest rates in a currency union to fall in inflation in one of the member countries. On the other hand, we thus do not consider effects of monetary policy, a key channel of impact of wage changes on aggregate demand in their model. Modelling changes in interest rates, possibly as consequence of monetary policy, is one of the most immediate possible future extensions of our model.

In Gali & Monacelli (2016), the authors also point to importance of interplay between wage and price stickiness. Such consideration might have notable significance in our model, too, since deflation and the evolution of real wages were shown to be one of the key components for crisis recovery in our model. The current version of the model is well accommodated for implementation of such price flexibility experiments. However, we deemed them to be out of the scope of the current work.

Next, we performed only informal exploratory analysis of exchange rate impacts. More thorough analysis might uncover subtle effects of exchange rates on the results of our analysis. Also, more comprehensive study of monetary unions, especially in the case of LS world, could be beneficial for bringing new insights in comparison to the existing literature.

We did not consider forceful devaluation of exchange rates of countries in crisis. On the contrary, our modelled exchange rates have balancing effects on international trade, as they lead to appreciation of the currency of the net exporter relatively to the currency of the net importer.

More generally, in contrast to the large body of discussed literature in the Chapter 2, we also do not consider fiscal policy impacts. Our model is a no-growth model, so we do not consider impacts on rates of growth. We also do not control for multiple issues considered in literature on international trade as impacting economic growth, such as gains from ability to specialize in production, effects of increased competition on firms' productivity, increases in investments and capital stock, firms' learning by exporting and/or importing etc. All of these are areas of potential future developments.

Chapter 5

Conclusion

In this thesis we examined stabilization role of wage flexibility, an open question in the macroeconomic theory with possibly important political consequences. We contribute to the existing literature by examining complexly interacting open economies which undergo economic crises characterized by debt-deflation.

Importance of debt-deflation for the examined question has often been rather neglected in the existing literature despite its high relevance. While falling prices can have positive effects on demand, they also lead to increased real value of debts, possibly starting a cascade of self-defeating deleveraging and bankruptcies. We built on Seppecher & Salle (2015) to fill this hole in the literature for the case of open economies.

International trade is of particular interest for the research question mainly due to the competitiveness channel. As falling wages lead to more competitive prices on foreign markets, increased exports can induce economic recovery. Indeed, our results suggest that foreign trade does have a stabilizing effect on economies in crises. However, feedback effects between trading partner often lead to business cycle synchronizations and spread of crises from country to country. Consideration of such complex interactions between trading countries in our model also constitutes an interesting contribution to the literature on open economies more generally, as the latter usually utilizes small open economy models in which the small country has no or only very limited effects on the rest of the world.

We provided a multi-country agent-based model based on Seppecher & Salle (2015) and Dosi *et al.* (2019). Our model follows Seppecher & Salle (2015) in replication of wide variety of macro and microeconomic stylized facts under the baseline settings. We examined scenarios that provided results robust to different trading settings and sizes of countries.

We performed comprehensive analysis of the model's results. Findings of this thesis suggest positive role of wage stability in recovery from debt-deflation crises. Moreover, benefits of stable wages extend through international markets towards trading partners with more flexible wages. This remains true even under relatively low levels of trade.

Meanwhile, economies of large countries have strong impact on economies of their small trading partners and are considerably more stable. Their firms are in times of crises able to offload excessive supply abroad with sizeable negative impact on the small country's firms' sales, while the analogous effects in the opposite case are much less powerful.

Our results also show that crises in countries that trade with each other are less severe on average, although at the same time their severity is more volatile, than in otherwise identically designed closed analogous of those countries. This suggests countries do, on the whole, help each other to get out of the crises through international trade.

Bibliography

Alvin, H. (1953): *A Guide to Keynes.* McGraw-Hill, New York.

Andrés, J., O. Arce, D. Thaler, & C. Thomas (2020): "When fiscal consolidation meets private deleveraging." *Review of Economic Dynamics* **37**: pp. 214–233.

Benigno, P., G. B. Eggertsson, & F. Romei (2014): "Dynamic debt deleveraging and optimal monetary policy." *Technical report*, National Bureau of Economic Research.

Benigno, P. & F. Romei (2014): "Debt deleveraging and the exchange rate." *Journal of International Economics* **93(1)**: pp. 1–16.

Bhattarai, S., G. Eggertsson, & R. Schoenle (2014): "Is increased price flexibility stabilizing? redux." .

Caiani, A., E. Catullo, & M. Gallegati (2018): "The effects of fiscal targets in a monetary union: a multi-country agent-based stock flow consistent model." *Industrial and Corporate Change* **27(6)**: pp. 1123–1154.

Caiani, A., A. Godin, E. Caverzasi, M. Gallegati, S. Kinsella, & J. E. Stiglitz (2016): "Agent based-stock flow consistent macroeconomics: Towards a benchmark model." *Journal of Economic Dynamics and Control* **69**: pp. 375–408.

Caverzasi, E. & A. Godin (2013): "Stock-flow consistent modeling through the ages." *Levy Economics Institute of Bard College Working Paper* **(745)**.

Chen, S., M. Kim, M. Otte, K. Wiseman, & A. Zdzienicka (2015): "Private sector deleveraging and growth following busts." *Available at SSRN 2572489* .

CHIARELLA, C. & C. DI GUILMI (2017): "Monetary policy and debt deflation: some computational experiments." *Macroeconomic Dynamics* **21(1)**: pp. 214–242.

CUERPO, C., I. DRUMOND, J. LENDVAI, P. PONTUCH, & R. RACIBORSKI (2015): "Private sector deleveraging in europe." *Economic Modelling* **44**: pp. 372–383.

DE LONG, J. B. & L. H. SUMMERS (1985): "Is increased price flexibility stabilizing?" .

DE SOYRES, F. & A. GAILLARD (2019): "Trade, global value chains and gdp comovemement: An empirical investigation." *World Bank Policy Research Working Paper* **(9091)**.

DOSI, G. & A. ROVENTINI (2019): "More is different... and complex! the case for agent-based macroeconomics." *Journal of Evolutionary Economics* **29(1)**: pp. 1–37.

DOSI, G., A. ROVENTINI, & E. RUSSO (2019): "Endogenous growth and global divergence in a multi-country agent-based model." *Journal of Economic Dynamics and Control* **101**: pp. 101–129.

EGGERTSSON, G., A. FERRERO, & A. RAFFO (2014): "Can structural reforms help europe?" *Journal of Monetary Economics* **61**: pp. 2–22.

EGGERTSSON, G. B. & P. KRUGMAN (2012): "Debt, deleveraging, and the liquidity trap: A fisher-minsky-koo approach." *The Quarterly Journal of Economics* **127(3)**: pp. 1469–1513.

EICHER, T. S. & D. J. KUENZEL (2016): "The elusive effects of trade on growth: Export diversity and economic take-off." *Canadian Journal of Economics/Revue canadienne d'économique* **49(1)**: pp. 264–295.

FARHI, E., G. GOPINATH, & O. ITSKHOKI (2014): "Fiscal devaluations." *Review of Economic Studies* **81(2)**: pp. 725–760.

FERRARI, A. (2019): "Global value chains and the business cycle." *Available at SSRN 3249434* .

FISHER, I. (1933): "The debt-deflation theory of great depressions." *Econometrica: Journal of the Econometric Society* pp. 337–357.

FORNARO, L. (2018): "International debt deleveraging." *Journal of the European Economic Association* **16(5)**: pp. 1394–1432.

FRANKEL, J. A. & A. K. ROSE (1998): "The endogenity of the optimum currency area criteria." *The economic journal* **108(449)**: pp. 1009–1025.

FRIEDMAN, M. (1953): "The case for flexible exchange rates." *Essays in positive economics* **157(203)**: p. 33.

GALI, J. (2013): "Notes for a new guide to keynes (i): wages, aggregate demand, and employment." *Journal of the European Economic Association* **11(5)**: pp. 973–1003.

GALI, J. & T. MONACELLI (2016): "Understanding the gains from wage flexibility: the exchange rate connection." *American Economic Review* **106(12)**: pp. 3829–68.

GALLEGATI, M. & A. KIRMAN (2012): "Reconstructing economics: Agent based models and complexity." *Complexity Economics* **1(1)**: pp. 5–31.

GATTI, D. D., G. FAGIOLO, M. GALLEGATI, M. RICHIARDI, & A. RUSSO (2018): *Agent-based models in economics: a toolkit.* Cambridge University Press.

GIRAUD, G. & A. POTTIER (2016): "Debt-deflation versus the liquidity trap: the dilemma of nonconventional monetary policy." *Economic Theory* **62(1)**: pp. 383–408.

HABERLER, G. V. (1936): *Theory of international trade: With its applications to commercial policy.* William Hodge and Company Limited, London.

HICKS, J. (1937): "Mr. keynes and the" classics"; a suggested interpretation." *Econometrica* **5(2)**: pp. 147–159.

JUSTINIANO, A., G. E. PRIMICERI, & A. TAMBALOTTI (2015): "Household leveraging and deleveraging." *Review of Economic Dynamics* **18(1)**: pp. 3–20.

KEYNES, J. M. (2020): *Obecna teorie zamestnanosti, uroku a penez.* Cicero.

KING, M. (1994): "Debt deflation: Theory and evidence." *European Economic Review* **38(3-4)**: pp. 419–445.

LEOMBRUNI, R. & M. RICHIARDI (2005): "Why are economists sceptical about agent-based simulations?" *Physica A: Statistical Mechanics and its Applications* **355(1)**: pp. 103–109.

LIN, L., D. P. TSOMOCOS, & A. P. VARDOULAKIS (2015): "Debt deflation effects of monetary policy." *Journal of Financial Stability* **21**: pp. 81–94.

LÓPEZ, J. (2020): "Wage flexibility, exchange-rate competitiveness and full employment: The first heretics." *Revista de Economia Contemporânea* **24(2)**: pp. 1–22.

MELITZ, M. J. (2003): "The impact of trade on intra-industry reallocations and aggregate industry productivity." *econometrica* **71(6)**: pp. 1695–1725.

MINSKY, H. P. (1975): *John Maynard Keynes, reprinted 2008.*

MINSKY, H. P. & H. KAUFMAN (2008): *Stabilizing an unstable economy*, volume 1. McGraw-Hill New York.

NEISSER, H. (2016): *Some international aspects of the business cycle.* University of Pennsylvania Press.

PIGOU, A. (1933): *Theory of unemployment.* Macmillan.

PILKINGTON, P. (2014): "Keynesâ€™ liquidity preference trumps debt deflation in 1931 and 2008." [Online; posted 24-February-2014].

RABERTO, M., A. TEGLIO, & S. CINCOTTI (2012): "Debt, deleveraging and business cycles: An agent-based perspective." *Economics: The Open-Access, Open-Assessment E-Journal* **6**.

RICCETTI, L., A. RUSSO, & M. GALLEGATI (2015): "An agent based decentralized matching macroeconomic model." *Journal of Economic Interaction and Coordination* **10(2)**: pp. 305–332.

SCHMITT-GROHÉ, S. & M. URIBE (2016): "Downward nominal wage rigidity, currency pegs, and involuntary unemployment." *Journal of Political Economy* **124(5)**: pp. 1466–1514.

SEPPECHER, P. (2012): "Flexibility of wages and macroeconomic instability in an agent-based computational model with endogenous money." *Macroeconomic Dynamics* **16(S2)**: pp. 284–297.

Seppecher, P. & I. Salle (2015): "Deleveraging crises and deep recessions: a behavioural approach." *Applied Economics* **47(34-35)**: pp. 3771–3790.

Shiller, R. J. (2013): "Irving fisher, debt deflation, and crises." *Journal of the History of Economic Thought* **35(2)**: pp. 179–183.

Shimer, R. (2012): "Wage rigidities and jobless recoveries." *Journal of Monetary Economics* **59**: pp. S65–S77.

Singh, T. (2010): "Does international trade cause economic growth? a survey." *The World Economy* **33(11)**: pp. 1517–1564.

Stockhammer, E. & Ö. Onaran (2012): "Rethinking wage policy in the face of the euro crisis. implications of the wage-led demand regime." *International Review of Applied Economics* **26(2)**: pp. 191–203.

Wagner, J. (2012): "International trade and firm performance: a survey of empirical studies since 2006." *Review of World Economics* **148(2)**: pp. 235–267.

Appendix A

Additional comments

Robustness of c and L values: We experimented with different choices of L and c values. Specifically, for q in the range from 20 to 40, we tried to use $q-$th average percentiles of employment rate as L-values, and c-values in the range from 2 to 4. Our results seem to be qualitatively robust to these alternatives. Moreover, results based on our main points of comparison of different scenarios – mean depths of crises – seem to be qualitatively robust to different choices of L and c values, i.e. if country X has on average deeper crises than country Y given our choices of L and c values than it has so for different reasonable choices of these values as well. By reasonable choices we mean average $20-40th$ percentile of employment rates for $L-value$ and $2-4$ percentage points for c value.

Interpretation of crises lengths: Among others, we report on mean total time spend in crises per simulation. For interpretation purposes it is important to realize that if we put c value equal to zero, by our definition of the crisis total time spend in crises should be on average approximately one fourth (345 periods) of the simulation length . Hence, the difference of the measured total time spend in crises and 345 gives a rough measure of how often does employment rate of a country show an insignificant deviation from the stability area which does not lead to a full-blown crisis. In other words, how many false crisis signals c-value filters out.

Appendix B

Additional results

B.1 Tables

Table B.1: 1-country and MM model, descriptive statistics of crises measures

	mean	min	median	max	std
base-base					
L-value C0	90.02	88.5	90.2	90.8	0.4900
L-value C1	90.00	88.5	90.1	90.8	0.5000
bottoms C0	81.75	73.3	82.5	87.0	3.3000
bottoms C1	81.87	72.6	82.8	87.0	3.3100
lengths C0	74.70	22.0	78.0	124.0	20.4400
lengths C1	76.40	23.0	80.0	126.0	21.3900
time C0	263.30	78.0	255.0	448.0	71.8300
time C1	266.30	85.0	264.0	429.0	71.5800
count C0	3.50	1.0	3.0	6.0	1.0397
count C1	3.50	1.0	3.0	6.0	0.9912
1-C model base					
L-value C0	90.65	89.08	90.8	91.4	0.4700
bottoms C0	80.43	75.80	80.4	87.6	1.9000
lengths C0	84.50	34.00	86.0	115.0	10.6100
time C0	256.40	84.00	256.0	423.0	72.6900
count C0	3.00	1.00	3.0	5.0	0.8487
alt1-alt1					
L-value C0	85.21	82.2	85.2	88.3	1.1900
L-value C1	85.22	82.2	85.2	88.8	1.1700
bottoms C0	76.41	66.3	76.3	82.2	3.6900
bottoms C1	76.98	69.0	77.4	82.2	3.4900
lengths C0	77.70	17.0	81.0	129.0	24.0200
lengths C1	77.40	16.0	81.0	134.0	24.4200
time C0	312.30	154.0	318.0	421.0	57.6000
time C1	317.20	157.0	322.0	430.0	51.9700
count C0	4.00	2.0	4.0	7.0	0.8203
count C1	4.10	2.0	4.0	6.0	0.8145
1-C model alt					
L-value C0	85.92	81.9	86.18	89.4	1.9500
bottoms C0	76.72	71.2	76.70	81.6	2.0400
lengths C0	96.70	49.0	94.00	199.0	22.8500
time C0	334.60	162.0	324.00	485.0	66.0800
count C0	3.50	2.0	3.00	5.0	0.5888

Note: Descriptive statistics for crisis measures across given wage flexibility setting and country. MM model scenarios are simulated with the baseline trade settings. Time refers to total time spend in crises per simulation. Count refers to number of crises per simulation.

Table B.2: 1-country vs MM models t-tests

scenario 1	scenario 2	measure	H_0	test	p-value
base-base	1-C model base	mean bottoms	C0 = C0	2-sample t-test	<0.0001
base-base	1-C model base	mean bottoms	C1 = C0	2-sample t-test	<0.0001
alt1-alt1	1-C model alt	mean bottoms	C0 = C0	2-sample t-test	0.1019
alt1-alt1	1-C model alt	mean bottoms	C1 = C0	2-sample t-test	0.6008
base-base	1-C model base	L-value	C0 = C0	2-sample t-test	<0.0001
base-base	1-C model base	L-value	C1 = C0	2-sample t-test	<0.0001
alt1-alt1	1-C model alt	L-value	C0 = C0	2-sample t-test	0.0121
alt1-alt1	1-C model alt	L-value	C1 = C0	2-sample t-test	0.0139

Note: Scenario 1 and 2 indicate from which scenarios the compared data come, H_0 indicates which country's data are compared and what is the null hypothesis. For example C1=C0 indicates that we test equality of the measure for the second country from the scenario 1 with the measure for the first country in the scenario 2.

Table B.3: MM baseline trade scenarios, descriptive statistics of monthly export rates

	min	mean	max	std	mean inner std	std of inner std
base-base						
country 0	0.0100	0.0107	0.0114	0.0003	0.0062	0.0004
country 1	0.0099	0.0107	0.0112	0.0003	0.0062	0.0004
alt1-alt1						
country 0	0.0100	0.0106	0.0113	0.0003	0.0066	0.0004
country 1	0.0099	0.0105	0.0113	0.0003	0.0065	0.0004
base-alt1						
country 0	0.0092	0.0096	0.0101	0.0002	0.0057	0.0002
country 1	0.0113	0.0119	0.0125	0.0003	0.0069	0.0004
base-alt2						
country 0	0.0088	0.0092	0.0098	0.0002	0.0054	0.0002
country 1	0.0126	0.0143	0.0171	0.0009	0.0080	0.0007

Table B.4: MM base-alt1 and base-alt2 scenarios with the baseline trade settings, descriptive statistics of crises measures

	mean	min	median	max	std
base-alt1					
L-value C0	89.87	88.6	89.9	90.8	0.3800
L-value C1	89.39	87.8	89.4	90.3	0.5000
bottoms C0	82.52	72.1	83.2	86.8	3.0100
bottoms C1	80.95	70.9	81.6	86.3	3.3700
lengths C0	76.10	20.0	76.0	130.0	22.3600
lengths C1	72.30	16.0	78.0	120.0	23.9700
time C0	256.90	80.0	255.0	424.0	61.3500
time C1	272.10	107.0	272.0	433.0	60.8100
count C0	3.40	1.0	3.0	5.0	0.8771
count C1	3.80	2.0	4.0	6.0	0.9455
base-alt2					
L-value C0	90.4200	89.80	90.4	90.9	0.2000
L-value C1	89.4500	88.68	89.4	90.2	0.3100
bottoms C0	82.2800	71.90	82.4	87.4	3.9400
bottoms C1	81.1800	66.20	83.5	86.4	5.2800
lengths C0	115.8000	22.00	126.0	205.0	49.4400
lengths C1	74.1000	14.00	46.0	194.0	51.0300
time C0	182.4000	90.00	176.0	313.0	39.9200
time C1	210.7000	60.00	206.0	308.0	48.4000
count C0	1.5743	1.00	1.0	4.0	0.7623
count C1	2.8000	1.00	3.0	5.0	1.1835

Table B.5: MM baseline trade scenarios, t-tests of mean crisis bottoms

scenario 1	scenario 2	measure	H_0*	test	p-value
base-base	base-base	mean bottoms	C0 = C1	pairwise t-test	0.5337
base-base	alt1-alt1	mean bottoms	C0 = C0	2-sample t-test	<0.0001
base-base	alt1-alt1	mean bottoms	C0 = C1	2-sample t-test	<0.0001
base-base	alt1-alt1	mean bottoms	C1 = C0	2-sample t-test	<0.0001
base-base	alt1-alt1	mean bottoms	C1 = C1	2-sample t-test	<0.0001
base-base	base-alt1	mean bottoms	C0 = C0	2-sample t-test	0.0021
base-base	base-alt1	mean bottoms	C0 = C1	2-sample t-test	0.0041
base-base	base-alt1	mean bottoms	C1 = C0	2-sample t-test	0.0268
base-base	base-alt1	mean bottoms	C1 = C1	2-sample t-test	0.0006
base-base	base-alt2	mean bottoms	C0 = C0	2-sample t-test	0.933
base-base	base-alt2	mean bottoms	C0 = C1	2-sample t-test	0.0003
base-base	base-alt2	mean bottoms	C1 = C0	2-sample t-test	0.5213
base-base	base-alt2	mean bottoms	C1 = C1	2-sample t-test	<0.0001
alt1-alt1	alt1-alt1	mean bottoms	C0 = C1	pairwise t-test	0.1046
alt1-alt1	base-alt1	mean bottoms	C0 = C0	2-sample t-test	<0.0001
alt1-alt1	base-alt1	mean bottoms	C0 = C1	2-sample t-test	<0.0001
alt1-alt1	base-alt1	mean bottoms	C1 = C0	2-sample t-test	<0.0001
alt1-alt1	base-alt1	mean bottoms	C1 = C1	2-sample t-test	<0.0001
alt1-alt1	base-alt2	mean bottoms	C0 = C0	2-sample t-test	<0.0001
alt1-alt1	base-alt2	mean bottoms	C0 = C1	2-sample t-test	<0.0001
alt1-alt1	base-alt2	mean bottoms	C1 = C0	2-sample t-test	<0.0001
alt1-alt1	base-alt2	mean bottoms	C1 = C1	2-sample t-test	<0.0001
base-alt1	base-alt1	mean bottoms	C0 = C1	pairwise t-test	<0.0001
base-alt1	base-alt2	mean bottoms	C0 = C0	2-sample t-test	0.013
base-alt1	base-alt2	mean bottoms	C0 = C1	2-sample t-test	<0.0001
base-alt1	base-alt2	mean bottoms	C1 = C0	2-sample t-test	0.0326
base-alt1	base-alt2	mean bottoms	C1 = C1	2-sample t-test	0.0556
base-alt2	base-alt2	mean bottoms	C0 = C1	pairwise t-test	0.0002

*on the left - measure for given country from scen. 1, on the right - from scen. 2

Table B.6: LS baseline trade scenarios, summary of employment correlations and BC synchronization metrics

variables	mean	min	median	max	std
base-base					
employment across*	0.8214	0.1996	0.8422	0.9325	0.0914
BC metric	0.7739	0.4911	0.7755	0.9398	0.0815
alt1-alt1					
employment across*	0.9254	0.8716	0.9303	0.9548	0.0168
BC metric	0.8553	0.6637	0.8690	0.9449	0.0645
base-alt1					
employment across*	0.8621	0.6138	0.8739	0.9383	0.0469
BC metric	0.7929	0.5391	0.7966	0.9526	0.0751
alt1-base					
employment across*	0.8163	0.6476	0.8212	0.8820	0.0440
BC metric	0.6271	0.2265	0.6419	0.8818	0.1151
base-alt2					
employment across*	0.8165	0.2237	0.8372	0.9154	0.0958
BC metric	0.7613	0.5298	0.7737	0.8976	0.0820
alt2-base					
employment across*	0.3770	0.1444	0.3516	0.7007	0.1256
BC metric	0.2774	0.0000	0.2674	0.5385	0.1108
*corr. between countries 0 and 1					

Table B.7: LS baseline trade settings, descriptive statistics of yearly export rates

	min	mean	max	std	mean inner std	std of inner std
base-base						
country 0	0.0208	0.0211	0.0215	0.0001	0.0021	0.0003
country 1	0.1018	0.1037	0.1058	0.0008	0.0141	0.0016
alt1-alt1						
country 0	0.0199	0.0202	0.0206	0.0001	0.0023	0.0002
country 1	0.0970	0.0996	0.1021	0.0011	0.0159	0.0011
base-alt1						
country 0	0.0219	0.0223	0.0228	0.0002	0.0027	0.0003
country 1	0.1109	0.1131	0.1162	0.0011	0.0152	0.0015
alt1-base						
country 0	0.0212	0.0220	0.0227	0.0003	0.0029	0.0004
country 1	0.0956	0.0976	0.1000	0.0009	0.0271	0.0042
base-alt2						
country 0	0.0238	0.0244	0.0253	0.0003	0.0032	0.0003
country 1	0.1216	0.1256	0.1304	0.0020	0.0168	0.0016
alt2-base						
country 0	0.0219	0.0231	0.0250	0.0008	0.0051	0.0021
country 1	0.0938	0.0952	0.0967	0.0007	0.0239	0.0017

Table B.8: LS baseline trade settings, descriptive statistics of crises measures

	mean	min	median	max	std
base-base					
L-value C0	91.20	89.58	91.20	91.7	0.3800
L-value C1	87.96	87.00	88.00	88.7	0.3900
bottoms C0	82.69	77.80	82.65	87.4	1.7100
bottoms C1	80.22	71.60	79.90	84.9	2.8000
lengths C0	87.70	46.00	88.00	115.0	9.8400
lengths C1	61.10	8.00	66.00	110.0	23.7300
time C0	211.90	0.00	197.00	425.0	87.4600
time C1	184.50	0.00	192.00	347.0	74.0200
count C0	2.40	0.00	2.00	5.0	1.0076
count C1	3.00	0.00	3.00	6.0	1.3124
alt1-alt1					
L-value C0	87.90	84.3	88.3	90.4	1.6200
L-value C1	85.39	82.8	85.6	87.2	1.0900
bottoms C0	78.50	74.1	78.4	84.6	1.6800
bottoms C1	75.72	68.7	75.6	82.3	2.6600
lengths C0	99.80	42.0	100.0	143.0	14.2900
lengths C1	83.90	9.0	87.0	141.0	25.0000
time C0	317.30	149.0	314.0	487.0	73.0000
time C1	284.90	120.0	283.0	433.0	68.2200
count C0	3.20	2.0	3.0	5.0	0.6807
count C1	3.40	2.0	3.0	5.0	0.7845
base-alt1					
L-value C0	90.93	89.1	91.0	91.6	0.4800
L-value C1	87.72	85.9	87.8	88.8	0.5400
bottoms C0	82.61	76.4	82.4	87.8	1.7300
bottoms C1	79.51	71.4	79.0	84.7	3.1700
lengths C0	87.90	49.0	89.0	131.0	10.8500
lengths C1	62.20	5.0	70.0	112.0	25.3000
time C0	247.20	74.0	252.0	460.0	81.3500

Continued on next page

Table B.8 – continued from previous page

	mean	min	median	max	std
time C1	221.60	65.0	215.0	386.0	71.9200
count C0	2.80	1.0	3.0	5.0	0.9088
count C1	3.60	1.0	3.0	8.0	1.3454
alt1-base					
L-value C0	89.23	87.28	89.0	91.3	0.9400
L-value C1	86.87	85.78	86.9	88.1	0.5300
bottoms C0	80.30	73.10	80.3	86.1	2.6800
bottoms C1	80.99	72.40	81.6	83.8	2.4900
lengths C0	60.40	23.00	59.5	111.0	16.0800
lengths C1	44.00	7.00	40.0	125.0	22.2800
time C0	302.50	72.00	316.0	447.0	83.6100
time C1	216.50	55.00	213.0	366.0	72.7800
count C0	5.00	1.00	5.0	7.0	1.3386
count C1	4.90	1.00	5.0	8.0	1.6452
base-alt2					
L-value C0	91.18	90.5	91.20	91.7	0.2800
L-value C1	88.19	87.0	88.20	89.0	0.3700
bottoms C0	83.65	78.7	83.90	87.6	1.9400
bottoms C1	80.67	70.9	80.55	85.1	2.9000
lengths C0	88.90	41.0	89.00	137.0	14.7800
lengths C1	62.20	6.0	69.00	118.0	26.3900
time C0	212.20	0.0	192.00	371.0	78.7900
time C1	188.30	0.0	183.00	344.0	65.6000
count C0	2.40	0.0	2.00	4.0	0.8897
count C1	3.00	0.0	3.00	6.0	1.1031
alt2-base					
L-value C0	89.21	88.3	89.2	89.9	0.3100
L-value C1	82.74	81.4	82.4	85.3	1.0200
bottoms C0	76.76	52.5	79.4	86.2	8.5200
bottoms C1	77.60	70.2	78.2	79.7	1.9700
lengths C0	88.10	21.0	68.0	213.0	53.5900
lengths C1	37.50	5.0	30.0	146.0	23.2400

Continued on next page

Table B.9: LS baseline trade settings, t-tests for mean crisis bottoms

scenario 1	scenario 2	measure	H_0*	test	p-value
base-base	base-alt1	mean bottoms	C0 = C0	2-sample t-test	0.742
base-base	base-alt1	mean bottoms	C1 = C1	2-sample t-test	0.0009
base-base	alt1-base	mean bottoms	C1 = C0	2-sample t-test	0.0767
base-base	base-alt2	mean bottoms	C1 = C1	2-sample t-test	0.0218
alt1-alt1	alt2-base	mean bottoms	C1 = C0	2-sample t-test	0.0123
alt1-base	alt1-base	mean bottoms	C0 = C1	pairwise t-test	0.0051
alt1-base	base-alt2	mean bottoms	C0 = C1	2-sample t-test	0.4226
alt1-base	base-alt2	mean bottoms	C1 = C1	2-sample t-test	0.1314

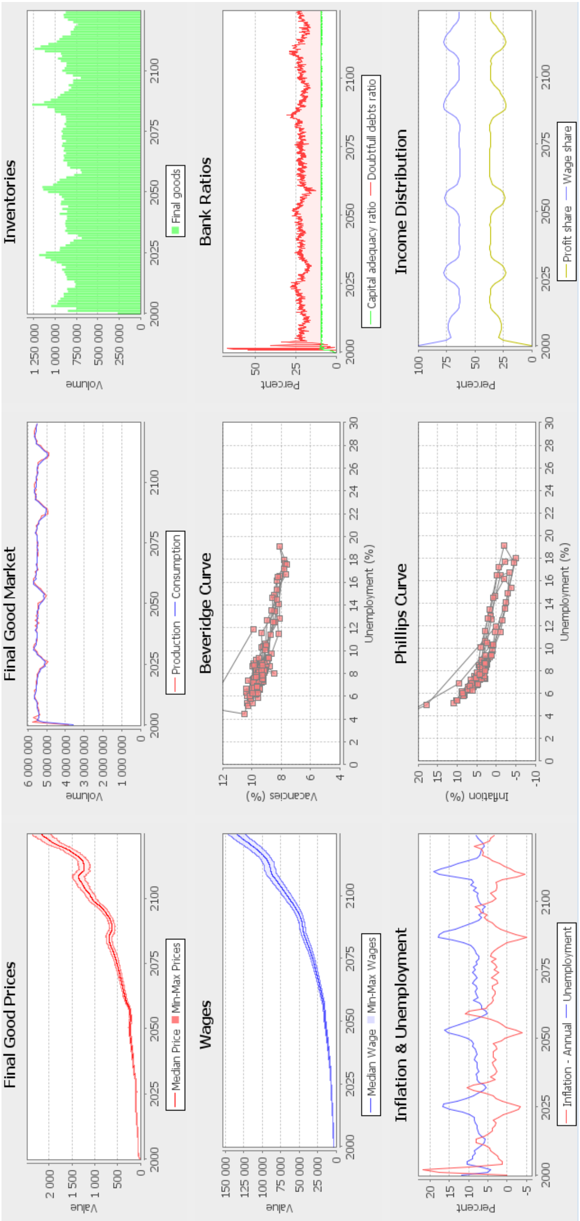
Note: *on the left - measure for given country from scenario 1, on the right - from scenario 2. Tests with p-value < 0.0001 were excluded

Table B.8 – continued from previous page

	mean	min	median	max	std
time C0	224.30	120.0	215.0	379.0	51.4400
time C1	214.00	0.0	214.0	400.0	100.6700
count C0	2.50	1.0	2.0	5.0	1.2783
count C1	5.70	0.0	6.0	12.0	2.3500

B.2 Figures

Figure B.1: Baseline scenario results from the original JAMEL application



Note: Labels on x-axis represent years with the beginning in 2000.

Figure B.2: Author's 1-country model baseline scenario time series

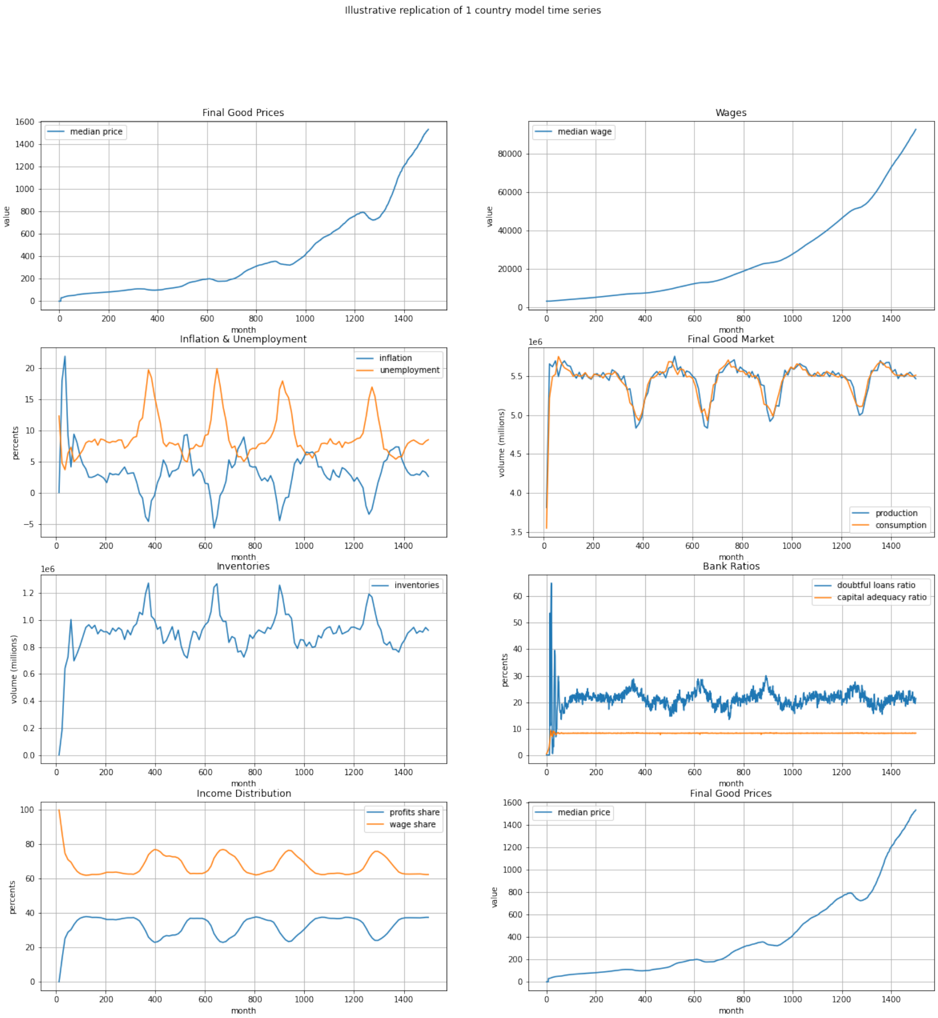


Figure B.3: Author's 1-country model baseline scenario Phillips and Beveridge curves

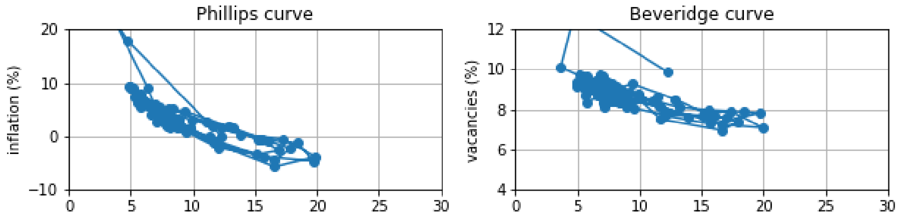
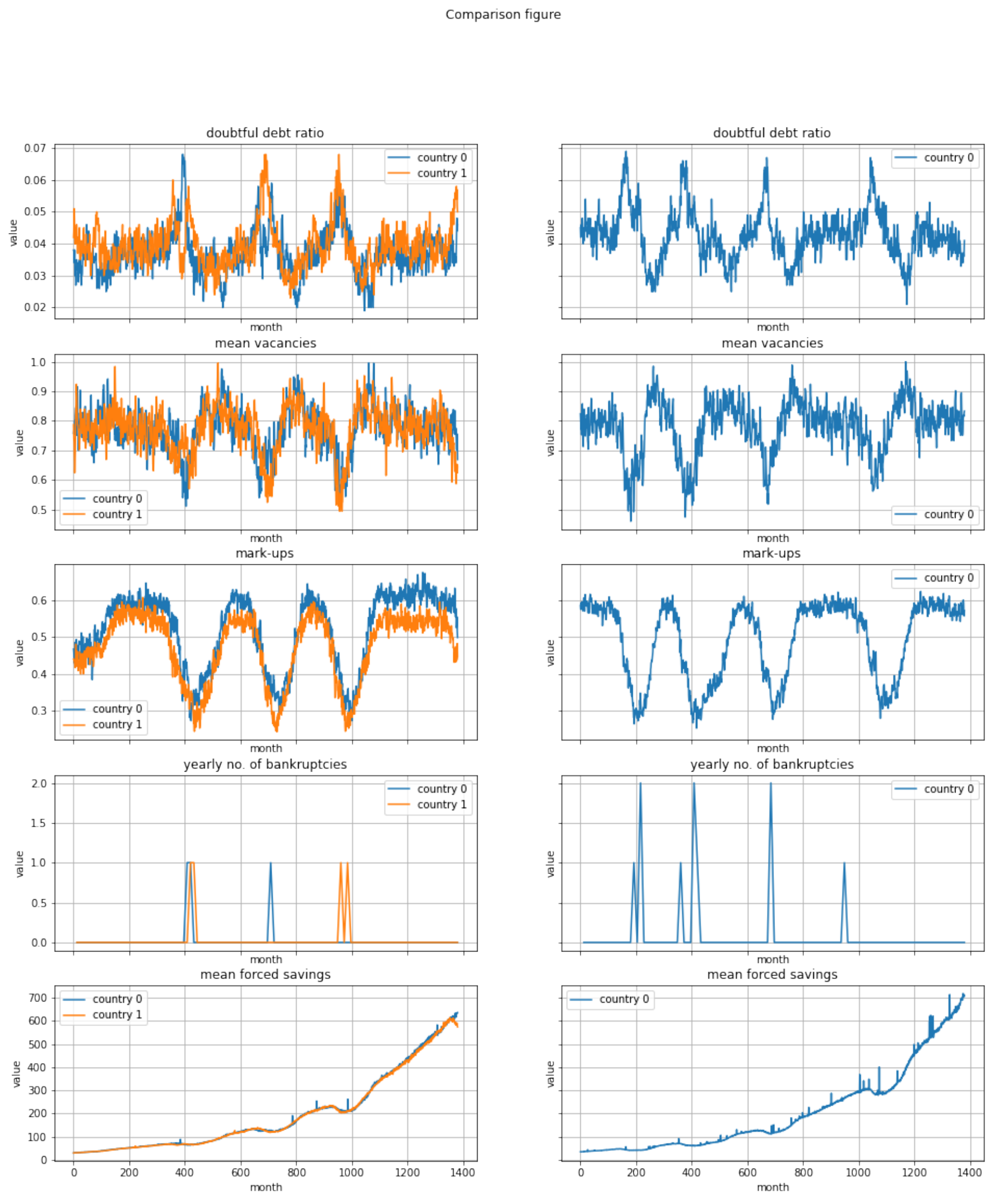
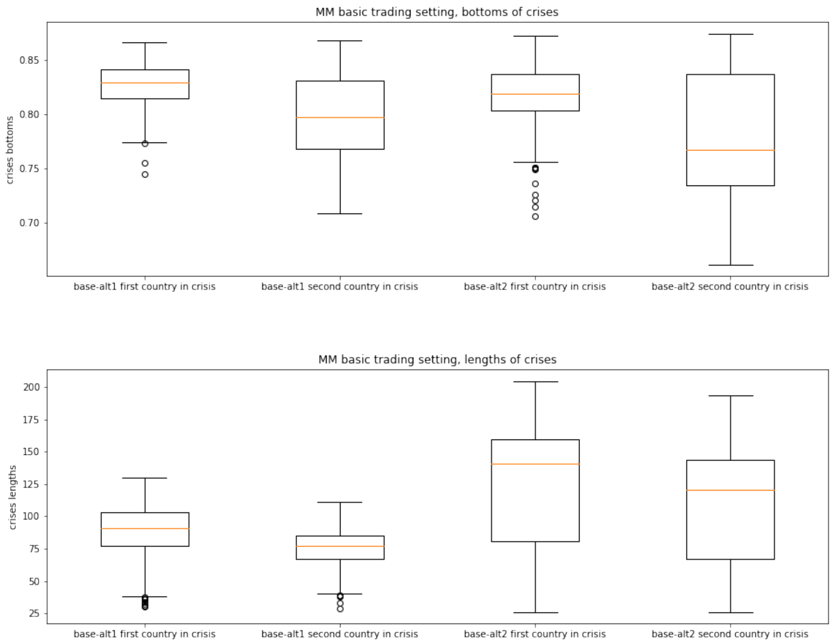


Figure B.4: Comparison of the baseline scenarios in 2 and 1-country models, part 2



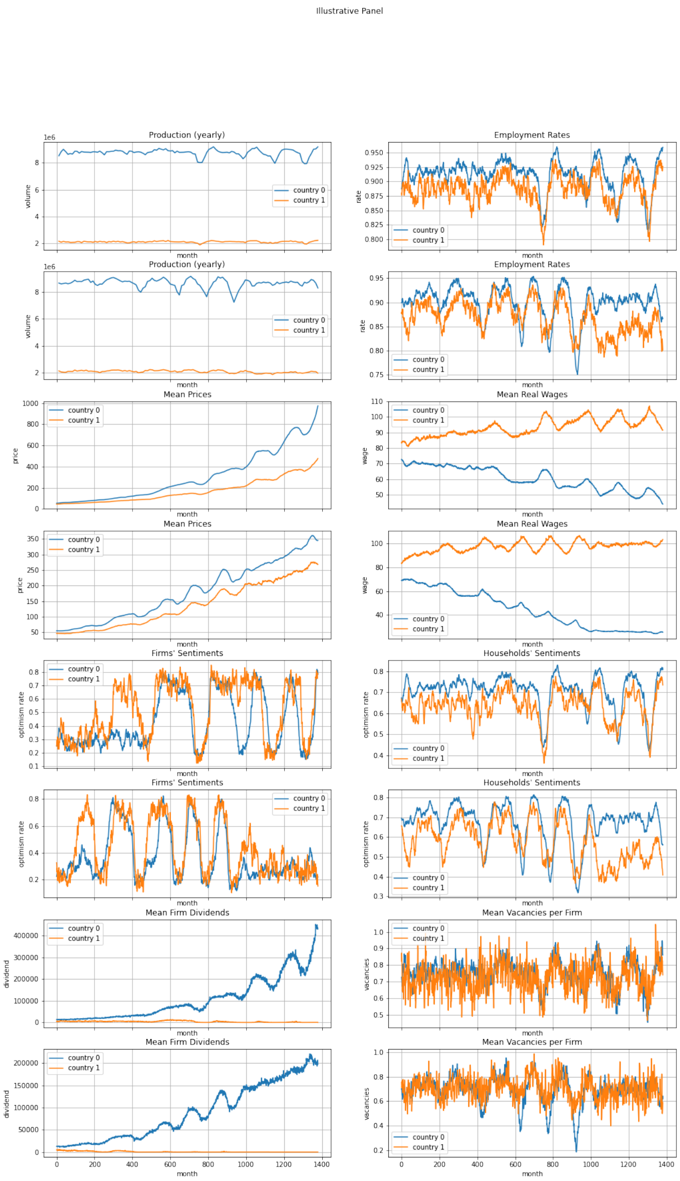
Note: On the left are data from a simulation of MM scenario with the baseline wage and trade settings in both countries. On the right are data from 1-country model with the baseline wage flexibility. Figure of bankruptcies show number of firms going bankrupt during a year.

Figure B.5: Boxplots of crisis bottoms and lengths w.r.t. order of entrance into crisis, MM mixed wage scenarios



Note: First country in crisis stands for whichever country entered the recession during a global crises sooner. Data across all global crises from MM scenarios with the baseline trade and mixed wage settings.

Figure B.6: Illustrative panel for LS alt1-base and alt2-base scenarios with the baseline trade settings



Note: In each pair of rows, data from alt1-base scenario are in the upper row, those from the alt2-base scenario are in the lower row.

Appendix C

Internet Appendix

Python codes and examples of simulated data related to this thesis are available at

`https://github.com/amacejovsky/Diploma-Thesis`