Three Essays on International Trade and Productivity

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A thesis presented for the degree of
Doctor of Philosophy

Durham University

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May 2019

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Abstract

In this thesis I examine, through three papers, the links between international trade and productivity. Two of these papers examine the impact of international trade on productivity and the final paper examines the impact of productivity on the patterns of international trade.

The first paper investigates the extent to which changes in the origin of a country's imports impact productivity, once changes in the overall volume of trade are accounted for, through an examination of the impact of the shift in UK imports away from the EU and towards Non-EU countries around the time of the Great Recession on UK productivity. The second paper analyses the impact of the endogenous response of less productive non-trading domestic firms on the behaviour of labour productivity in response to macroeconomic shocks, through the development of a new DSGE model of trade and productivity. The third paper explores the extent to which the relative bilateral flows of international trade are explained by relative productivity differences, i.e. the extent to which these flows are driven by Ricardian Comparative Advantage.

The key findings of this thesis are: first, changes in the origin of a country's imports can significantly impact its productivity, even once changes in the overall volume of trade are accounted for. Second, the endogenous response of less productive non-trading domestic firms is a key driver of the response of productivity to macroeconomic shocks. Third, although Ricardian Trade Theory holds across a wide range of countries and industries, consistent with the existing literature, only a very small percentage of the relative bilateral flows of international trade can be explained by differences in relative productivities.

Declaration

The work in this thesis is based on research carried out at the Department of Economics and Finance in Durham University Business School, England. No part of this thesis has been submitted elsewhere for any other degree or qualification and it is all my own work unless referenced to the contrary in the text, or where it is otherwise clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

The material presented in Chapters 3 and 4 in this thesis were written as collaborations with Dr Anamaria Nicolae and Professor Stephen Millard, while the material presented in all other chapters is entirely my own work. I contributed approximately 70 percent of the work in Chapter 3 and 70 percent of the work in Chapter 4.

The work in this thesis was funded by an Collaboarative PhD Studentship from the ESRC, whose support is gratefully acknowledged.

Acknowledgements

There are many people that I need to thank for their help, guidance and support both academically and personally over the course of my PhD:

First, I am immensely grateful to my Primary Supervisor Dr Anamaria Nicolae. She has provided me with so much support, advice, guidance and encouragement both on my PhD studies as well as my wider academic experience, for which I will be always grateful. The number of hours that we have spent discussing every aspect of my research, and the number of times she has provided invaluable advice have set me up superbly, not just for this thesis, but for the academic career I am pursuing in the future. Second, I must say thank you to my Collaborative Supervisor Professor Stephen Millard. He has been another invaluable source of support, advice, guidance and encouragement. Problems that would have taken me months to work through have been solved in minutes through his input. I will always be thankful that he agreed to take me on as his student, supported me in the engagement I have had with his work, and the wider work of the Bank of England. Third, I would like to thank Professor Dennis Phillip for his valuable help and support. I would also like to thank Dr Leslie Reinhorn for his extremely helpful comments on earlier drafts of my papers.

Next, I must express my gratitude to all of the friends that I have made during my time at Durham. To all of my friends from Ooook! Productions in particular, but Durham Student Theatre more generally, I must say an enormous thank you for all of the amazing times I have had, and for the friendship and happiness you have given me along the way.

Finally, I must say thank you to two more individuals. Thank you to my mother, Sally, and my partner, Victoria, for everything you have done and the love you have both given me. The unwavering support from both of you has brought me through all of the difficult times over the past few years, and having both of you in my life means that I am certain of being able to face any difficult times I have in the future, I love you both so much.

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Chapter 1

Introduction

This thesis seeks to contribute to the understanding of the links between trade and productivity. The existing literature has shown that trade and productivity are linked in both directions: the level of productivity and changes in productivity impact the flows of international trade, and the flows of international trade impact productivity at both the macroeconomic and microeconomic levels. To motivate the research to be undertaken for the purpose of this thesis a comprehensive review of the existing literature examining the links between trade and productivity is presented, as well as a review of the current explanations for the slowdown in UK productivity after the Great Recession, known as the UK Productivity Puzzle, in order to further motivate the analysis in the first paper of the thesis, as well as the application at the end of the second paper. Several key results and notable gaps stand out from the analysis of the existing literature:

1. Although existing research has thoroughly investigated the impact of import volumes on productivity (see for example Hung *et al.* (2004), Amiti and Konings (2007) and Bloom *et al.* (2016)) and this impact is well understood, the role of the origin of a country's imports on productivity has not been previously examined. In Chapter 3 of this thesis I examine whether changes in average per-unit barriers to imports resulting from shifts in the origin of a country's imports can result in changes in productivity even when trade volumes are constant. Given that changes in barriers to imports can have significant effects on productivity, understanding the impact of changes

in trade barriers due to shifts in import origin is necessary to accurately predict the impact of changes in the patterns of international trade on the importing country's economy. Despite the many explanations for the UK Productivity Puzzle that have been put forward, so far, no analysis of the impact of changes in international trade has been conducted. Given that the persistent weakness in UK productivity growth is of key concern to both fiscal and monetary policymakers, understanding the drivers of this weakness, including the potential impact of trade changes, is of vital importance for the development of future policy and therefore the strength of an economy.

2. While the impact of international trade on domestic trading firms has been extensively investigated, in both the empirical literature (see for example Aw *et al.* (2000), De Loecker (2007) and Bernard, Redding and Schott (2007)) and the theoretical literature (see for example Ghironi and Melitz (2005), Cacciatore (2014), and Fattel Jaef and Lopez (2014)), the impact of international trade on non-trading firms is not yet well understood. Given that such firms make up the majority of the firms in all economies, for example in the UK they make up 88% of firms, the entry and exit of the non-trading firms from the domestic market can have significant effects on the behaviour of productivity and other macroeconomic variables. Theoretical models which do not allow for the endogenous entry and exit of less productive non-trading firms, such as those of Ghironi and Melitz (2005) or Fattel Jaef and Lopez (2014), are not able to account for the observed significant increase in productivity that results from increases in imports, examined in papers such as Hung *et al.* (2004) and Bloom *et al.* (2016). In such models, although productivity does vary in response to changes in barriers to imports, barriers to exports have a much larger impact, contrary to empirical observations. Thus, accurately modelling the endogenous behaviour of less productive firms is vital when assessing both the impact of changes in barriers to trade, as well as the response of productivity to various domestic macroeconomic shocks.

3. Third, none of the previous empirical tests of Ricardian Trade Theory (see for example MacDougall (1951), Bhagwati (1964) and Costinot *et al.* (2012)) can determine the extent to which relative bilateral flows of international trade can be explained by differences in relative productivity levels. Although this literature can analyse whether or not Ricardian Comparative Advantage drives a proportion of the relative bilateral flows of international trade, they cannot determine how large this proportion is. In order to assess the gains from trading according to Ricardian Trade Theory it is necessary to assess the extent to which trade follows Ricardian Comparative Advantage, rather than an analysis of only whether the theory holds. Assessing the gains from trade is of key concern to academics as well as fiscal and monetary policymakers.

In this thesis, the three gaps presented above, are addressed as follows: In Chapter 3 of this thesis the circumstances in which changes in the origin of a country's imports will impact that country's productivity are established. The specific case of the decrease in the proportion of UK imports that originated in the EU around the time of the Great Recession is then examined, and the extent to which this import origin shift impacted UK productivity and thus can contribute to our understanding of the slowdown in UK productivity after the Great Recession, known as the UK Productivity Puzzle is estimated.

In Chapter 4 of this thesis a new theoretical Dynamic Stochastic General Equilibrium (DSGE) model, building on Ghironi and Melitz (2005) is developed to incorporate an endogenous response of less productive non-trading domestic firms to macroeconomic shocks. This model is then used to examine the response of labour productivity to various macroeconomic shocks, including a comparison of the relative impact of changes in barriers to imports compared to the impact of changes in barriers to exports. As highlighted above, the previous theoretical literature was unable to match the observed large increases in productivity in response to reductions in barriers to imports seen in the empirical literature such as Bloom *et al.* (2016) which is captured in this model through the endogenous response of less productive non-trading firms.

In Chapter 5 of this thesis I adopt the innovative theoretical framework developed by Costinot *et al.* (2012) to present the first empirical test of the extent to which Ricardian Comparative Advantage drives the relative bilateral flows of international trade. I conduct this analysis across a wide range of countries and industries, including both goods and services industries. I then re-run the analysis across various sub-samples of industries and countries, and then conduct a meta-analysis on the results from these sub-samples in order to explore the driving factors behind deviations from Ricardian Trade Theory.

Three key results stand out from my analysis: First, the decrease in the proportion of UK services imports originating in the EU around the time of the Great Recession was exogenously driven by changes in tastes, and caused around a 1.7% decrease in UK productivity, but the decrease in the proportion of UK goods imports originating in the EU at the same time had no effect on UK productivity. Second, the entry and exit of less productive non-trading firms into the domestic market means that barriers to imports cause larger changes in productivity than changes in barriers to exports, and can also drive an endogenous persistence in labour productivity in response to macroeconomic shocks. Third, although Ricardian Comparative Advantage does drive trade across a wide range of countries and industries, it can only explain a very small percentage of the relative bilateral flows of international trade.

The outline of the remainder of the thesis is as follows: Chapter 2 presents a comprehensive review of the existing literature examining the links between trade and productivity, and a review of the current explanations for the slowdown in UK productivity after the Great Recession, known as the UK Productivity Puzzle. Chapter 3 examines the extent to which a change in the origin of UK imports, around the time of the Great Recession, from the EU to Non-EU countries may have caused decreases in UK productivity. Chapter 4 presents a new theoretical model, building on Ghironi and Melitz (2005), that seeks to examine the impact of the entry and exit of less productive non-trading domestic firms on labour productivity and its persistence in response to macroeconomic shocks. Chapter 5 examines the extent to which relative bilateral flows of international trade can be explained by differences in relative productivities, and thus to what extent these flows are driven by Ricardian Comparative Advantage. Chapter 6 concludes.

Chapter 2

Literature Review

2.1 Introduction

There has been an extensive literature that has analysed the interactions between flows of international trade and labour productivity. This literature can be broken down into three groups: first, a literature than examines how the level of productivity and changes in productivity impact both the composition and volumes of international trade. Second, a literature that examines how flows of international trade affect labour productivity at both an aggregate and firm level. Third, theoretical models of international trade and productivity that seek to incorporate key findings from both of the first two literature groupings. In this chapter I present a comprehensive review of these groups of literature, as well as a review of the literature on the causes of the persistent weakness in UK productivity growth since the Great Recession, known as the UK Productivity Puzzle, in order to offer further motivation to Chapter 3 and the application in Chapter 4.

2.2 The Impact of Productivity on Trade

2.2.1 Introduction

In this section, I will present a review of the literature that examines the impact of the level of productivity and changes in productivity on international trade. The first examination of the impact of productivity on international trade was put forth by David Ricardo in his 1817 work '*On the Principles of Political Economy and Taxation.*' (See Ricardo (1817).). There has subsequently been much theoretical and empirical examination of this theory, which links differences in relative productivities to the flows of international trade. In addition to this wide literature, there is also a significant body of both empirical and theoretical literature that examines the impact of a firm's productivity level on its propensity to 'Self-Select' into international trade. In this section I will provide an overview of both of these bodies of literature.

2.2.2 Ricardian Trade Theory

David Ricardo in his 1817 work '*On the Principles of Political Economy and Taxation.*' put forward what has come to be know as Ricardian Trade Theory, or trade according to Ricardian Comparative Advantage, (See Ricardo (1817).). The original theory consists of a two country two good numerical example, using the example of the UK and Portugal, and the production of wool/cloth and wine. In this theory, countries should trade on the basis of their relative productivities, that is their productivities in one industry relative to another. To maximise welfare, countries completely specialise in the good in which they have a comparative advantage i.e. the good that they can produce at a lower opportunity cost relative to another country, even if they do not have an absolute advantage in either good. If countries specialise according to their comparative advantage and then trade for the other good, then both countries are able to have higher levels of consumption post-trade than pre-trade.

Although Ricardian Trade Theory was outlined in 1817, given the lack of clear empirical predictions, and the shortages of reliable data on trade and productivity, the first empirical test of Ricardian Trade Theory was not conducted until 1951. MacDougall (1951) conducted the first empirical test of the theory using what was subsequently known as the 'Third-Country Method'. In this method, relative productivities in different industries in two countries are compared to the relative exports of those two countries to a 'third country', usually the rest of the world. In MacDougall (1951), relative exports in 25 manufacturing industries from the US and UK to the rest of the world are compared. In 20 out of 25 industries, once relative wage rates are adjusted for, relative exports match the relative productivity levels, thus leading to the conclusion that Ricardian Trade Theory was empirically valid.

The empirical validity of Ricardian Trade Theory was also supported by subsequent empirical testing of the theory, such as MacDougall (1952), Balassa (1963), Stern (1962) and MacDougall *et al.* (1962). All of these studies utilised the 'Third-Country Method' with US data and different years of observation, correcting for further cross country variation. Balassa (1963) updated the data source used in MacDougall (1951) to 1950 data, Stern (1962) offered improvements in relative productivity measurement and MacDougall *et al.* (1962) corrected for relative tariff differentials. In all of the papers, even once the data was updated, and the empirical methodology improved, they still concluded that their analysis provided empirical evidence in favour of Ricardian Trade Theory. The analysis of Balassa (1963) was re-run, using more modern econometric techniques by Yoon (2011), who concluded that the result still offered empirical support for Ricardian Trade Theory. The 'Third-Country Method' was also used by Kreinin (1969), however, utilising different country pairs, specifically Canada/UK, Canada/US and Canada/Australia. Unlike the earlier studies, none of the three pairings provided statistically significant evidence in favour of Ricardian Trade Theory.

One of the main drawbacks of the earlier empirical testing of Ricardian Trade Theory was the reliance on the 'Third-Country Method', which as Bhagwati (1964) highlighted, lacked strong theoretical underpinnings. Bhagwati (1964) stated that "*It is difficult to see, for instance, the theoretical reason why the ratio of the two rival's third-market exports should, in a cross-section analysis, turn out to increase as the corresponding price ratio falls.*" p.11. Given the inability of the 'Third-Country Method' to account for differences in elasticities of substitution and different demand levels, this criticism represents a major failing of the earlier empirical literature, and calls into question all results based on the 'Third-Country Method'.

The empirical validity of Ricardian Trade Theory was also called into question by other later studies, including Sailors and Bronson (1970) and McGilvray and Simpson (1973). Sailors and Bronson (1970) analysed 13 industries in 19 countries, giving 342 country pairs for both logarithmic and non-logarithmic correlations. When Ricardian Trade Theory was tested for each of these country pairs 196 out of 342 non-logarithmic correlations and 188 out of 342 logarithmic correlations have the incorrect sign. They therefore concluded that there was no evidence in favour of Ricardian Trade Theory. McGilvray and Simpson (1973) examined 34 sectors in the UK and Ireland in 1963 using Spearman's Correlation Coefficient. Using this method 10 out of 12 correlations had the incorrect sign and none were statistically significant They therefore concluded that there was no evidence in favour of Ricardian Trade Theory.

More recently, several papers have found qualified evidence in favour of Ricardian Trade Theory. Golub and Hsieh (2000) and Altzinger and Damijan (2009) both conducted empirical tests of Ricardian Trade Theory and concluded that there was statistically significant evidence in favour of the theory. Golub and Hsieh (2000) examined Ricardian Trade Theory using data on total export ratios, bilateral trade, labour productivity and unit labour costs. Across their different specifications all of the empirical analyses gave statistically significant evidence in favour of Ricardian Trade Theory. Altzinger and Damijan (2009) examined the extent to which Ricardian Trade Theory was able to explain the patterns of intra-EU trade, and found that, once capital to labour ratios were accounted for, the short run patterns of intra-EU trade could be explained by Ricardian Trade Theory. However, the long-run patterns of trade appeared to be driven by other structural determinants, rather than by labour productivity.

However, both of these more recent studies, as well as the earlier work, building on MacDougall (1951), as well as both Sailors and Bronson (1970) and McGilvray and Simpson (1973), suffered from a lack of strong theoretical foundations for their empirical analysis, which limited the extent to which their analysis can be said to be an accurate evaluation of Ricardian Trade Theory. The lack of strong theoretical foundations for empirical tests of Ricardian Trade Theory was addressed by Costinot *et al.* (2012). In their paper Costinot *et al.* (2012) develop a theoretical framework that allows for intra-industry heterogeneity as in Eaton and Kortum (2002), and outline theoretically consistent empirical tests of Ricardian Trade Theory. Conducting these empirical tests they conclude that there is significant evidence that Ricardian Trade Theory holds in the patterns of international trade. However, the significant limitation of their analysis is that, although they can conclude whether or not Ricardian Trade Theory holds in the patterns of international trade, the methodology they adopt means that they can draw no quantitative conclusions on the proportion of relative bilateral trade flows that are driven by relative productivity differences i.e. Ricardian Comparative Advantage.

2.2.3 Self-Selection Hypothesis

One of the most empirically supported hypotheses in the international trade literature is the self-selection hypothesis, which states that firms that trade internationally are more productive upon entry to international markets than those that do not. The first empirical testing of this hypothesis was presented by Bernard *et al.* (1995), who examined US plants, and found that those plants that exported were on average more productive than equivalent plants that did not export. In order to determine the causal relationship from higher productivity to self-selection into exporting, Bernard and Jensen (1999) replicate the initial analysis of Bernard *et al.* (1995), confirming their original findings, before extending the analysis by comparing firms that moved from producing only domestically to exporting over the period of their sample, with otherwise equivalent firms that produced only domestically over the entire sample period. They found that those firms that moved into exporting were indeed more productive than those firms that remained only in domestic markets, and thus concluded that there was strong causal support for the self-selection hypothesis.

This strong relationship between the productivity of firms and the propensity of the firms to engage in international trade has been subsequently confirmed by many other empirical analyses. Delgado *et al.* (2002) examine a panel of Spanish firms from 1991-1996, and find strong evidence in favour of the self-selection hypothesis, in both labour productivity and TFP. Arnold and Hussinger (2010) and Andersson *et al.* (2008) analysed firms in Germany and Sweden respectively. Both, again, find significant evidence in favour of the self-selection hypothesis. Sharma and Mishra (2015) conduct a micro-level analysis of Indian firms for 1994-2006 and found statistically significant evidence in favour of the self-selection hypothesis.

These country level studies were supported by the comprehensive literature reviews conducted by Wagner (2007, 2012). In these reviews all of the examined studies, including Kimura and Kioyota (2004) and Damijan *et al.* (2004) find statistically significant evidence in favour of the self-selection hypothesis. The overwhelming evidence in the literature is for a causal relationship from higher firm level productivity to participation in exporting activities. There is also evidence, albeit more limited, that this relationship extends to importing firms as well. Muuls and Pisu (2009) examine data from Belgium, and Vogel and Wagner (2011) examine data from Germany, and find that both importers and exporters are more productive than non-trading firms, and that those firms that engage in both importing and exporting are more productive than both sole importers and exporters. Wales *et al.* (2018) support these findings, using data from HMRC and find that exporting firms are again more productive than non-trading firms, but less productive than importing firms, who are in turn less productive than firms that both import and export.

In contrast to the vast majority of the literature, there are a small number of studies, such as Bernard and Wagner (1997) and Aw *et al.* (1997) that do not find statistically significant evidence in favour of self-selection. In both these papers firms that export have higher initial productivities, but not to a statistically significant degree. However, these studies suffer from data limitations, in particular more limited sample sizes than many of the later analyses. Therefore, the overall conclusion of the literature is that the self-selection effect is both accurate and key to any examination of trade and productivity.

The reviews by Wagner (2007, 2012) also found that studies on the relative impact of the self-selection hypothesis have focused on 'single-country' analysis, mainly due to difficulties with the compatibility of differing national data sources. This causes issues with making broad claims about the validity of self-selection. However, given the wide range of countries examined within the literature this criticism is less applicable, and thus the conclusion remains that the self-selection hypothesis is empirically supported.

2.2.4 Conclusion

To summarise, in this section, I have reviewed the literature that examines the impact of the level of productivity and changes in productivity on international trade. I have shown that this literature can be divided into two groups, first, theoretical and empirical examinations of Ricardian Trade Theory, and second, empirical examinations of the impact of firm level productivity on trade. The first group showed that Ricardian Trade Theory does hold, when tested in a theoretically consistent framework. The second group predominantly focuses on the self-selection hypothesis, where firms that are relatively more productive self-select into exporting and importing. The self-selection hypothesis is overwhelmingly supported. However, significant gaps remain in both of these groups, including, specifically, a lack of examination of the extent to which international trade flows are driven by Ricardian Comparative Advantage.

2.3 The Impact of Trade on Productivity

2.3.1 Introduction

In this section I present a review of the existing literature that analyses the impact of international trade on productivity. A wide body of literature sought to determine the impact of a country's openness on the speed of their development at the macroeconomic level for policy purposes. Due to the limitations of these studies in identifying causal relationships from trade to productivity a wide literature then emerged looking at the microeconomic, firm level impact of trade on productivity in order to explore the drivers of the link between openness and productivity. In this section I present a review of both the macroeconomic and microeconomic studies of the impact of international trade on productivity.

2.3.2 Macroeconomic Empirical Studies

The initial motivation of studies on trade and productivity was to determine whether openness to trade was a necessary condition for long term economic growth. The policy implications from these studies were on the impact of national trade policies, rather than policies targeted at specific firms or industries, due to a lack of firm level analysis.

In the pre-2000 studies the main methodology adopted was cross country analysis, rather than time series analysis. Although this enabled conclusions to be drawn about the impact of differences in openness it meant that other country specific factors were ignored, which may have led to bias in these results. There was some debate whether the increases in productivity associated with openness to international trade operated via changes in TFP, as was claimed by Edwards (1998), or via changes in inputs, as in Dollar (1992) and Sachs and Warner (1995). However, the results of these studies were all similar in that they found that openness to trade was statistically significantly correlated with higher productivity levels, and productivity growth rates. This result is robust, for TFP, across time periods, functional form and estimation technique, as shown in Edwards (1998) and for other productivity forms across different time periods, as shown in Sachs and Warner (1995).

However, there are many drawbacks to the pre-2000 studies, most notably issues of: (1) endogeneity, (2) omitted variables such as institutional quality or geographic factors and (3) the direction of causation, for example in Lopez (2005). More recent studies sought to correct for these problems to obtain more accurate estimations for the trade-productivity effect. The impact of both the originally omitted variables of geography and institutional quality were accounted for by Noguer and Siscart (2005), and even once these had been factored into the calculations, openness was still significantly correlated to productivity growth. Similarly, Alcala and Ciccone (2004) find that even when institutional quality is accounted for, for the countries in their study the correlation between trade openness and productivity is both positive and statistically significant. The results in Alcala and Ciccone (2004) are robust to several different regression specifications, and point to the link between productivity and trade operating via TFP, rather than through increased inputs.

The drawbacks with the direction of causation and endogeneity were addressed in Frankel and Romer (1999). They used a measure of geographic characteristics of a country's trade to proxy for the trade levels of the country. Such characteristics are unrelated to income, and so, when used to obtain instrumental variable estimates of the impact of trade on productivity, remove the issues of endogeneity. Once these issues are accounted for the correlation between openness to trade and productivity growth remains, albeit with a reduced, but still high, level of statistical significance.

One method of correcting for the issue of causation identification is to use cointegration and Granger-causality techniques as in Marin (1992). Adopting this method enables the causal link to be identified, in addition to the level of correlation. Adopting this approach, she shows that the benefits to productivity growth of an 'outward looking' regime are large and statistically significant.

Although there are several drawbacks to the pre-2000 studies, these have been addressed in the more recent literature, with the correlation between greater openness to trade and greater productivity growth remaining. Feyrer (2009) uses a time-varying geographic instrument to estimate the elasticity of income to trade, and find that this elasticity is between 0.5 and 0.75, meaning that a 1% increase in trade leads to between a 0.5% and 0.75% increase in GDP per capita. Feyrer (2011) uses the closing of the Suez Canal as a natural experiment to estimate the elasticity of income to trade in goods, and finds that this elasticity is between approximately 0.15 and 0.25. The estimates from these two papers have been used extensively to model the potential impact of increased trade barriers that result from the UK's exit from the EU on UK productivity, see for example HM Treasury (2016), Sampson (2017) and Dhingra *et al.* (2017).

The extent to which this correlation holds for developing countries is an issue that has received specific attention in the literature. If the correlation holds for developing nations then the potential exists for using increased openness as a driver of economic growth for policy-makers in the developing world. The extent to which the correlation between openness and economic growth holds for developing countries was analysed in the review of the early literature by Havrylyshyn (1990). Much of the early literature, such as Kim and Park (1985) and Clague (1970), was qualitative in nature, comparing periods of high productivity growth to those periods in which governments were generally adopting outward orientated policies for their nations, and finding a general correlation between the two. Although this approach may have been necessary due to the unavailability of data on the degree of openness, and other measures of trade, the accuracy of the results is questionable at best.

This issue of the qualitative nature of the early literature was addressed by Harrison (1996), with a combination of cross-country and panel data regressions. Although the cross-country regressions did support the link between openness and productivity, this was not true for the panel-data regressions that included elements of time series analysis. The main cause of this difference highlighted was the significant fluctuations in trade regimes causing an issue of establishing any longer-run effect of trade on productivity. Although trade is likely to be correlated with higher productivity in the longer run, this is unlikely to be the case in the short run. Therefore, rapid fluctuations in trade regime may cancel out any positive effects and lead to insignificant correlations. However the long term correlation remains significant, and so in the long term policy-makers can increase the openness of their country's trade to promote productivity growth.

A more recent literature has sought to examine the specific impact of import volume changes on productivity. Hung *et al.* (2004) identify four channels through which imports could impact domestic productivity: economies of scale, competition effects, reallocation effects and spillover effects. They then conduct a panel analysis to determine first whether imports do impact on domestic productivity, and then second which of the channels is the most important in driving this effect. In their analysis they find that imports are indeed an important driver of productivity growth, and that it is the final three channels that drive this effect, rather than any changes in economies of scale. Bloom *et al.* (2016) conducted an analysis of the impact of the rise of imports into Europe from China after China's accession to the WTO on European productivity growth. They find that increased imports from China after the lowering of barriers to trade significantly increased the impact of import volumes on European productivity, and resulted in large increases in European productivity, that varied country by country dependent on the extent of the increase in trade between China and that individual country.

However, all of these macroeconomic studies fail to examine the impact of the origin and destination of a country's trade on the link between trade and productivity. Changes in the destination of exports and the origin of imports will impact the opportunities for information and knowledge spillovers, and could impact the extent to which competition from trade affects productivity, even if trade volumes are held constant. These studies also fail to examine the compositional effects of trade as well. Does trade in goods have the same impact on productivity as trade in services, and within these, does trade in certain industries result in larger knowledge and information spillovers than others?

2.3.3 Micro-Level Empirical Studies

Given the previously identified limitations of macroeconomic studies in identifying causal relationships from trade to productivity a literature emerged analysing the impact of trade on productivity at the microeconomic, firm level. There are four main strands of this microeconomic literature. The first strand of literature explores the learning-by-trading hypothesis, investigating whether firms that trade internationally have higher productivity growth rates than comparable non-trading firms. The second strand explores the effects of trade liberalisation on the relative impact of different links between trade and productivity. The last strand explores the impact of research and development on productivity growth via trade, and the mechanisms by which this occurs.

Learning-by-Trading Hypothesis

The first mechanism by which trade and productivity can be linked is the learning-by-trading hypothesis. By engaging in international trade firms have higher productivity growth rates, via some combination of learning from experiences in the foreign markets and better utilisation of foreign inputs and opportunities. Firms that do not engage internationally at all, or firms that cease to trade lose access to these benefits and so experience lower productivity growth rates. The literature is divided as to whether the hypothesis is accurate.

Of the papers that found significant evidence in favour of learning-by-trading some of the most supportive results are found in Hahn (2004), Kimura and Kioyota (2004) and De Loecker (2007). In their analysis of respectively Japanese, Korean and Slovenian firms they all found statistically significant evidence in favour of the learning-by-exporting hypothesis. This was supported by the reviews carried out by Wagner (2007, 2012), who highlighted the support for the learning-by-doing hypothesis for developed countries.

However, a large proportion of papers did not find significant evidence in favour of learning-by-trading. Several different countries have been analysed, to determine the extent to which learning-by-exporting can apply to different markets and levels of openness. Wagner (2007, 2012) conducts a review of the literature and highlights the analysis of Mexican firms from 1986-1990 by Bernard (1995), the analysis of Mexican firms from 1986-1990 by Clerides *et al.* (1998), and the analysis of Chinese firms from 1988-1992 by Kraay (2002), amongst others, as papers that find no evidence in favour of learning-by-exporting. Overall Wagner (2007, 2012) concludes that the evidence in favour of learning-by-exporting is mixed, and that no clear conclusions can be drawn about its validity. The analysis of learning-by-trading is extended to examine the impact of FDI on the validity of the hypothesis by Keller and Yeaple (2009). Once the flows of FDI are accounted for, which are positively correlated with increased productivity growth, there is no statistically significant link between a firm trading and increases in productivity growth for firms in the US between 1987 and 1996.

It is possible that firms that experience productivity gains after entering international markets may simply be experiencing an initial boost due to the economies of scale of larger markets, rather than any longer term benefits to productivity growth, according to Kostevc (2005). A heterogeneous firm model of trade and productivity is developed and then calibrated using Slovenian data from 1994-2002. Although firms do experience a boost to productivity in the years after they enter international markets this tails off rapidly, and is similar in behaviour to the boost experienced upon market expansion. Therefore it is likely that the boosts to productivity experienced by firms are as a result of increasing economies of scale, rather than any learning-by-exporting effect.

Crespi *et al.* (2008) examine a sample of UK firms taken from the Community

Innovation Survey. Although their results are supportive of the hypothesis that exporters learn from their customers and thus experience higher productivity growth rates, the results are only significant for certain specifications, specifically for those specifications with no control variables, suggesting a large degree of omitted variable bias. However, their results, which show that exporters have higher productivity growth rates and higher productivity levels, are significant for all specifications. This suggests that, overall, the higher productivity levels and higher growth rates observed for exporting firms are likely to be based on self-selection, where those firms with naturally high productivity levels are more likely to begin exporting, as Melitz (2003) predicts.

The result from Crespi *et al.* (2008) that the impact of self-selection on productivity is likely to be significantly higher than the impact of learning-by-trading is consistent with the findings of Greenaway and Kneller (2004), Harris and Li (2008) and Harris and Moffat (2015*b*). The exact extent to which learning-by-trading is significant varies among these studies, and for the various industries within these studies. However, they are all conclusive that the productivity differentials between exporters and non-exporters pre-date their entry into exporting markets. This provides further evidence in favour of the prominence of self-selection, in determining the impact of trade upon productivity, as Melitz (2003) predicts. The main changes in productivity as a result of changes in trade, are derived from movements in the distribution of firm productivity levels between firms, rather than movements in the productivity within firms.

To determine the extent to which the learning-by-trading hypothesis is valid for countries with different characteristics Martins and Yang (2009) conduct a meta-analysis of previous academic examinations of the topic. 33 studies (27 published and 6 working papers) which examine the learning-by-trading hypothesis are identified. The extent to which learning-by-trading is valid is extremely dependent on external factors. The hypothesis is supported to a much greater degree for developed countries, and for the first few years a firm exports, supporting the view of Kostevc (2005) that productivity growth benefits for exporters predominantly derive from market expansion effects.

These findings also go some way towards explaining the discrepancies between the results of the previously mentioned studies, as well as the discrepancies explored in Wagner (2007, 2012). Those studies that found little evidence in favour were indeed, in most cases (with the exception of Keller and Yeaple (2009)), those examining developing countries, or countries that straddled the threshold over the years of analysis and vice versa for studies analysing countries in the developed world.

Impact of Trade Liberalisation

The impact of changes in tariffs on the extent to which both the self-selection and learning-by-trading hypotheses are valid has been explored empirically. Trade barriers can cause the benefits from trade to be lost, and reduce the levels of learning-by-exporting that firms in those economies benefit from. The extent to which this is the case was examined for Canadian firms by Baldwin and Gu (2004). The analysis of the fall in both tariff and non-tariff barriers allowed the impact on productivity growth to be examined on a time series basis. As barriers to trade fell more firms started to export, and the benefits to the productivity growth of trading for existing trading firms increased. Firms also started to invest more in R&D to fully realise the benefits from this.

The changes from tariff reductions are analysed separately for output tariffs and input tariffs for Indonesian firms by Amiti and Konings (2007). The gains from the reductions in output tariffs mainly focus around increased import competition and economies of scale from access to wider markets. Gains from reductions in input tariffs are much more focussed on increased learning-by-exporting benefits, as well as variety and quality improvements for inputs. The relative gains from the two different types of tariff reductions are estimated, with the gains from a 10% fall in input tariffs estimated at around a 12% gain in productivity, approximately double the gains from a fall in output tariffs. The gains from the fall in input tariffs are derived from increased quality of imported intermediate inputs, which has more of an effect than learning-by-exporting.

The empirical methodology used in Amiti and Konings (2007) is modified to utilise changes in effective rather than nominal tariffs by Eslava *et al.* (2013). The analysis of Colombian trade reform for the years 1982-1998 finds that a reduction in effective tariffs has much more of an impact than a reduction in nominal tariffs. The reduction in the rate of tariff actually faced by firms causes the productivity growth benefits from learning-by-exporting to increase. Additionally after the tariff reductions firms' survival depends more closely upon a firm's intrinsic productivity level. Thus tariff reductions cause the average productivity level in an economy to increase.

All three papers have analysed the impact of falls in tariff and non-tariff barriers to trade, finding that reducing these barriers increases the learning-from-trading productivity growth benefits, and causes more firms to enter export markets. One interesting expansion would be an exploration of the impact of trade restrictions. Do trade restrictions simply work in the directly opposite way to trade liberalisation, or do other factors come into play to lessen the impact. The rise of non-tariff barriers since the financial crisis gives an opportunity to examine this, and can determine whether models should include any additional provisions above and beyond allowing shocks to the cost of trade in both directions.

Impact of Technology, Research and Development

International trade is also linked to productivity via Research and Development. There are two main mechanisms by which this occurs: firstly there is the theory that the levels of learning-by-trading benefits that a firm experiences is tied to their levels of research and development. Firms require a certain level of R&D in order to take advantage of the positive effects of trading on productivity growth, and the greater a firm's R&D the more it benefits from the learning-by-trading effect.

Secondly there is the spillover effects of foreign R&D on domestic productivity growth, via international trade. The rate of foreign R&D is tied to the rate of domestic productivity growth via an index of the productivity levels, firms that have higher levels of trade benefit more from foreign R&D.

The first mechanism, where the levels of learning-by-trading benefit are tied to a firm's level of R&D was examined by Aw *et al.* (2005). For Taiwanese firms it was found that firms that engaged in exporting had higher productivity growth rates than firms that did not, as learning-by trading would predict. However, of these firms, those that invest in R&D have substantially higher growth rates, suggesting that a level of R&D investment is necessary to fully realise the productivity growth benefits of trading.

The link between learning-by-trading benefits and R&D was then examined in direct comparison with the extent to which learning-by-trading is valid by Sharma and Mishra (2015). Although it is the case that more productive firms self-select, and that firms experience learning-by-trading, R&D offers a boost to productivity growth, above and beyond those experienced by firms that just trade. The increase in productivity from R&D is also higher for firms that trade compared to those that do not, suggesting that R&D offers a boost to the benefits from international spillovers.

The second mechanism by which R&D and trade interact is the impact of foreign R&D on domestic productivity growth via the spillovers from international trade. A proportion of the learning-by-trading benefits to productivity growth are derived from these spillovers which have been analysed in the literature. A theoretical model of these trade based R&D spillovers was developed by Coe and Helpman (1995). The model is then calibrated and tested using a cross section of data from OECD countries. The model shows that the rate at which a country's productivity growth rate is impacted by foreign investment in R&D is directly tied to the openness and rates of trade of that country.

The Coe and Helpman (1995) model was extended to correct for potential aggregation bias and indexation bias by Lichtenberg and Van Pottelsberghe de la Potterie (1998). An alternative weighting scheme is used, which both removes the potential bias and improves the empirical results. This is combined with a generalisation of the empirical framework that compares the output elasticity of foreign R&D to a country's openness to trade. These modifications improve the accuracy of the empirical testing, but do not change the outcome, it is still the case that countries with increased openness to trade experience greater foreign R&D spillovers.

The theoretical link was then tested empirically with UK industry level data for manufacturing firms from 1970 by Cameron *et al.* (2005). There is a statistically significant link between the domestic R&D levels and productivity, however, there is also a significant link between domestic productivity and foreign R&D. This link is tied to the levels of a firm's trading activities, suggesting increased spillover effects for firms the more they trade internationally.

In order for a model of international trade and productivity to have an accurate process for both of these mechanisms it is necessary to have a linkage between domestic productivity growth and the foreign rates of R&D/technology growth which is then indexed to the rate at which a firm trades internationally, in order to incorporate knowledge spillovers. This allows both the R&D impact on productivity to be affected by the rate of trade and allows the trade impact on productivity to be affected by the rate of R&D.

2.3.4 Conclusion

In this section I presented a review of the literature examining the impact of international trade on productivity at both the aggregate and firm level. Although the macro-level literature is conclusive that countries that engage in international trade have higher productivity levels than those that do not, there are a number of explanations as to why this is, such as the benefits of specialisation in Alcala and Ciccone (2004), increased economies of scale as in Caves (1980), increased competition from imports as in Bloom *et al.* (2016) and learning-from-trading as in Lopez (2005). However, the determination of the relative weight of each of these explanations, and the extent to which higher productivity levels represent a long term benefit from openness required a more micro/firm level analysis.

In section 2.3.3 we saw that, for developed countries, firms that engage internationally have higher rates of productivity growth, in addition to the higher initial productivity levels emerging from the self-selection effect examined in section 2.2.3. We also saw that trade liberalisation increases the magnitude of both of these effects, as does increased investment in R&D.

However, significant gaps remain in both the macroeconomic and microeconomic analyses of the impact of international trade on productivity, including an examination of the impact of changes in the origin/destination and industry composition of international trade at an aggregate level, and the channels through which learning-by-exporting could affect productivity, to determine whether this is through technology and knowledge spillovers, or simply through increased economies of scale.

2.4 Theoretical Models of International Trade and Productivity

2.4.1 Introduction

The section will critically analyse the theoretical models that explore the links between international trade and productivity. First, Krugman (1980) will be critically analysed, then the extensions to Krugman (1980), including Krugman (1990) and Ethier (1982). Second, the model in Melitz (2003) will be critically examined. This will be followed by the extensions to Melitz (2003), each of which addresses one of the limitations of the model in Melitz (2003). The limitations of Melitz (2003) can be broadly grouped into: 1) limitations regarding the modelling of the intensive and extensive margins of trade (Chaney (2008), Arkolakis *et al.* (2008), Hanson and Xiang (2008), Bernard *et al.* (2006*a*) and Mayer *et al.* (2014)); 2) the limited levels of firm level heterogeneity (Melitz and Ottaviano (2008), Melitz and Redding (2014)); 3) the limitation of the particular static equilibrium framework used in Melitz (2003) (Helpman *et al.* (2004), Bernard, Jensen, Redding and Schott (2007), Matsushima and Zhao (2015) and Cherkashin *et al.* (2015)) and 4) the fact that the model in Melitz (2003) is in a static environment, and so would need to be extended to a dynamic framework to analyse changes over time(Ghironi and Melitz (2005)).

The baseline models in international trade focussed predominately on the impact productivity has on trade rather than the reverse. In Ricardian Trade Theory trade flows between countries on the basis of comparative labour productivity levels. Countries export those goods in which they have the greatest comparative advantage. In the Heckscher-Ohlin (H-O) theory countries trade according to their relative factor abundances. However, although the Ricardian and H-O theories were able to explain a large proportion of the flows of international trade they were unable to account for intra-industry trade, or firm level differences.

2.4.2 Introduction of Intra-Industry Trade

Intra-industry trade, where firms trade with each other within industries, was extensively studied empirically by Grubel and Lloyd (1975). However, the earlier models of international trade could not account for this phenomenon. Krugman (1980) sought to explain this with the introduction of monopolistic competition, economies of scale and product differentiation. The presence of large quantities of intra-industry trade was confirmed by papers such as Davis and Haltiwanger (1991) and Dunne *et al.* (1989). In the model in Krugman (1980) firms produce differentiated products in a static general equilibrium framework with monopolistic competition. Consumers demand the varieties of goods produced by each firm, and economies of scale are introduced by a fixed cost of production which results in an average total cost that decreases as production increases, although average variable costs remain constant. The introduction of this product differentiation and economies of scale meant that a proportion of the international trade predicted by the model will be intra-industry trade.

However, the model in Krugman (1980) did have several limitations. In Krugman (1980) it is recognised that although the volume of trade can be predicted, the direction of trade remains to be determined. There are also limitations that were addressed in subsequent papers: Firstly, although the model predicts that due to product differentiation and economies of scale firms will trade on an intra-industry level, it does not predict the impact this will have on the wider economy. Krugman (1980) addresses the mechanisms of intra-industry trade, rather that the applications of this trade in a wider economy. Secondly, although the model helps to explain the impact of product differentiation, it does not examine the causes of this differentiation, for example this differentiation could be caused by productivity differences as in Ricardian Trade theory, or factor endowments as in H-O theory. Thirdly, although the firms in the model sell differentiated products they are homogeneous in other ways, particularly with regards to productivities, with all goods being produced with the same cost function, with equal marginal costs.

The model in Krugman (1980) was extended to address these limitations. Krugman (1990) extended the model in Krugman (1980) to address the first limitation, and explain the patterns of economic geography that emerge in developed nations, with manufacturing firms tending to focus into one location, resulting in a core-periphery pattern. This pattern appears when manufacturing firms become bunched together, but the primary goods firms remain dispersed due to the locations of resources. This results from a combination of transport costs and the economies of scale benefits from combining firms into one location. The model predicts that the extent to which the core-periphery pattern emerges is dependent on the levels of transportation costs, the proportion of national income from manufacturing and the extent of the economies of scale. The larger these factors are the greater the levels of manufacturing concentration, and so the larger the core-periphery pattern that emerges.

The second limitation was addressed in Ethier (1982). He combined the model from Krugman (1980) with factor endowment theories similar to H-O theory to develop a model to predict the relative impacts of product differentiation and scale economies vs. factor endowments in predicting the levels of intra-industry trade. The model simulates the interactions between the economies of scale internal to firms, and those that are derived internationally with the factor endowments in different economies and firms. Although economies of scale play some role in the determination of intra-industry trade the main determinant is the relative factor endowments of firms and countries. The model also predicts that changes to production as a result of interaction between national and international economies of scale will be predominately displayed via changes in the number of units of production, rather than the size of each individual unit.

Although firms are differentiated by the product they produce in Krugman (1980), they are not heterogeneous in productivity. Papers such as Bernard and Jensen (1999) and Aw *et al.* (2000) show that firms are, in fact, extremely heterogeneous with regards to productivity. This limitation of Krugman (1980) was addressed by Melitz (2003) who combined the model in Krugman (1980) with the heterogeneous firm model in Jovanovic (1982). The model in Melitz (2003) features firms that have heterogeneous productivity levels in a monopolistically competitive environment. Firms pay a fixed cost to begin production and then draw a productivity level from a distribution. Firms then make two decisions: firstly, whether or not to produce, and then whether or not to engage in international markets. They will produce if the productivity level they draw is above the cutoff level for production, and similarly with exporting and the cutoff level for engaging in international markets. The model predicts that those firms that are the most productive will self-select into the export markets, and those firms that are not productive enough to export, but are above the production cutoff level will just serve the domestic market. Exposure to international trade increases the average productivity level in a country, as it causes the production cutoff level of productivity to increase. However, there are no increases in the productivity of individual firms when a country becomes open to trade, only the average level of productivity. Alongside this limitation are several others that have been addressed in the literature.

2.4.3 Extension of Firm Level Heterogeneity

The first major limitation addressed was the reduced ability of the model in Melitz (2003) to examine the intensive and extensive margins of trade. These studies sought to determine the relative impact of international trade and productivity on both the quantity of goods that firms produced (intensive margin), as well as the number of different varieties of good produced by each firm (extensive margin). Chaney (2008) introduced both the intensive and extensive margins of trade and then focussed on the extensive margin of trade, introducing fixed export costs and adjustments solely to the extensive margin. They found that the impact of trade barriers is dampened by the elasticity of substitution. However, a high elasticity of substitution causes the initial productivity differences in Melitz (2003) to be translated into large differences in firm sizes.

Although Chaney (2008) modelled the extensive and intensive margins of trade, in their paper they did not then apply this to any specific economy. This application was done by Arkolakis *et al.* (2008), who applied the analysis to the consumer welfare problem. Data on Costa Rica was used to analyse the welfare changes from increased variety available to consumers as a result of decreased trade barriers. It was found that, although trade liberalisation did result in increased welfare as a result of increased variety, this increase was smaller than expected on the basis of the model in Chaney (2008) alone. This was explained via the reduced number of varieties produced by domestic firms after liberalisation, as the less productive domestic firms exited the market. They concluded that although the gains from a reduction in trade barriers are lower as a result of these domestic variety losses they are always compensated by increased variety from abroad.

Both Chaney (2008) and Arkolakis *et al.* (2008) focussed on the theoretical modelling of the intensive and extensive margins of trade, rather than examining them empirically. An empirical examination of these margins was carried out by Hanson and Xiang (2008). They examined the relative extent to which adjustments to trade occurred on the intensive margin vs. the extensive margin. It was found that, at least for US motion picture exports the adjustments occur more frequently along the intensive margin. Thus the model in Melitz (2003) has been modified to incorporate trade costs that were fixed worldwide, rather than fixed bilaterally. Fixing them in this manner allowed trade adjustments to occur more often on the intensive margin, and so improved the performance of the model when taken to data.

The model in Melitz (2003) has also been extended to allow for firms that produce multiple products to allow a more accurate analysis of the impact of productivity on the relative impact of the intensive and extensive margins of trade. Bernard *et al.* (2006*a*) develop a general equilibrium framework with firms that produced multiple products for a more accurate analysis. They then apply this model to an analysis of the impact of trade liberalisation on the intensive and extensive margins. Their model predicts that although larger firms do not produce as many varieties after liberalisation, they have a higher market share in the varieties that they do produce. The impact of these multi-product firms on a country's average productivity levels was analysed by Mayer *et al.* (2014). They introduced multi-product firms in a similar way to Bernard *et al.* (2006*a*), and then compared the productivity levels in autarky to the free trade equilibrium. They found that exposure to trade, when firms produce multiple products, causes similar effects to those in Melitz (2003), in that the least productive firms exit. However, the exposure also causes firms to concentrate on their most productive products and so causes firm average productivity to increase, thus amplifying the effect in

Melitz (2003).

The second major limitation of Melitz (2003) was the low levels of heterogeneity at firm level and at country level in the model as, although firms are differentiated by productivity in the model, in the real world firms have much higher levels of differentiation. Countries meanwhile in Melitz (2003) are assumed to be broadly homogeneous, with identical sizes and productivity distributions, which is again unrealistic in the real world.

The increased firm level heterogeneity was introduced by Melitz and Ottaviano (2008) via endogenously determined mark-ups between firms. They also endogenise the 'toughness' of competition across different markets. This 'toughness' is impacted by market size and the degree of openness to trade, and then feeds into the responses of firms in different markets to incremental increases in trade liberalisation. They then extend their initial model to a static general equilibrium framework with multiple asymmetric countries with asymmetric trade costs. This extension proves to be highly tractable and the authors conclude that the modelling framework they set out provides a suitable framework for any analysis of the impact of differing degrees of regional integration policy.

The country level heterogeneity was introduced by Melitz and Redding (2014). They allowed countries to vary in size, trade barriers, and productivity distribution. The addition of these elements allows reallocation between firms after trade liberalisation, which raises welfare above the basic reallocation in the model in Melitz (2003). These elements also allow further differentiation in the behaviour of exporters when compared to non exporters. All of these improvements improve the analytical applicability of the model and gives a better representation of the data.

The third major limitation consists of the manner in which firm modelling has been adopted in the static framework used by Melitz (2003), particularly the lack of intermediate good firms and FDI. Flows of FDI, in addition to the flows of goods were introduced by Helpman *et al.* (2004) to allow a mechanism of financial transfer. These FDI flows represented an alternate mechanism for firms to interact with foreign markets. This differentiates firms and adds a new layer to the base model in Melitz (2003). In the new form the most productive firms engage in international markets via FDI, rather than exporting, with firms that are less productive choosing to export. It also forces more firms to exit the market than the base model in Melitz (2003), providing a further boost to average productivity upon exposure to trade.

The static framework in Melitz (2003) was extended by its combination with the integrated equilibrium framework in Helpman and Krugman (1985) by Bernard, Jensen, Redding and Schott (2007). The resultant general equilibrium framework with asymmetric factor abundance between countries results in enhanced reactions to changes to trade barriers than in the model in Melitz (2003). In the extended version trade liberalisation causes enhanced creative destruction, and so enhanced increases in average productivity in those industries in which a country has the comparative advantage. This enhanced increase in average productivity raises the overall welfare gains from trade, although due to the increased job turnover rates these gains are not evenly distributed across all workers.

Although the model in Melitz (2003) performs relatively well when taken to data, papers such as Ghemawat *et al.* (2010) show that for relative export performance there is substantial room for improvement. Matsushima and Zhao (2015) sought to improve the performance of the model in this area by introducing intermediate retailers into the base model. When these retailers are introduced, and interact with both the consumer and the goods producer via simultaneous price negotiations, the performance of the model is substantially improved. Matsushima and Zhao (2015) test the predictions of their extended model compared to the model in Melitz (2003) and find statistically significant improvements in predictive power.

Cherkashin *et al.* (2015) endogenise the probability of firm death and introduce trade preference policies like subsidisation to improve the accuracy of the model to a static environment. They test the relative predictive power of their model compared to the base model in Melitz (2003) on Bangladeshi trade data. They conclude that their modifications result in a statistically significant improvement in the predictive power of the model.

The fourth limitation of the model in Melitz (2003) is its static framework. In this static framework the model cannot be used to model changes in firm and country behaviour over time. This limitation was addressed in Ghironi and Melitz (2005), who adapted the model in Melitz (2003) to a DSGE framework. They introduce an exogenous country level productivity factor that works in conjunction with the firm level productivity measure. In the dynamic framework firms behave as in the original model in Melitz (2003), however, they now maximise their profits over their expected lifetime. Ghironi and Melitz (2005) then analyse the impact of permanent increases in one country's productivity, and introduce international financial trading to analyse the impact of firm level heterogeneity on the Harrod-Ballassa-Samuelson effect. However, the model in Ghironi and Melitz (2005) does have several limitations: firstly, the model does not have endogenised productivity and therefore, although the model can predict the impact of changes in productivity on the wider economy, the converse is not true. Secondly, although the model can explain the changes in the flows of goods between two countries in response to productivity changes this is merely the volume of trade between the two countries. In order to model the changes in the destination of trade after a change in productivity a three country model would be needed. Thirdly, although firms and the countries are modelled as heterogeneous the consumers are unrealistically assumed to be homogeneous.

2.4.4 Conclusion

In this section I presented a review of the existing literature that developed theoretical models of international trade and productivity. These theoretical models have tried to incorporate stylised facts from the literatures examining the impact of trade on productivity and productivity on trade, such as the self-selection of more productive firms into international trade. The foundation of these models of trade and productivity was Melitz (2003), which has then been extended in many directions to try to account for different characteristics of international trade and the firms that engage in international trade. The most relevant extension for the purpose of this thesis is the extension by Ghironi and Melitz (2005) of the model in Melitz (2003) to a DSGE framework, to enable an examination of the dynamic behaviour of the economy to changes in international trade barriers and other macroeconomic shocks.

However, as with the previous empirical literature, significant gaps remain in this theoretical literature. There are significant limitations of the current theoretical models, including the unrealistic assumptions of consumer homogeneity and exogenously determined non-trading firm productivity. The second assumption in particular causes the models to be unable to match the significant response of productivity to increased volumes of imports, observable in studies such as Bloom *et al.* (2016).

2.5 The UK Productivity Puzzle

2.5.1 Introduction

Since the Great Recession (2008-2009) there has been a large shortfall between the measured level of UK productivity and the level that a continuation of the pre-crisis trend would predict. This type of shortfall between actual productivity and an extrapolation based on the pre-crisis trend productivity growth levels is referred to in ONS releases as the 'productivity gap.' (See ONS (2015).). In 2015 this productivity gap was around 13% (ONS (2015)), and as of 2017 Q3 had widened to 16%, according to the ONS. The unusual and increasing size of this productivity gap has subsequently come to be known in the literature as the UK Productivity Puzzle (Barnett *et al.* (2014) and Bryson and Forth (2015)). Barnett *et al.* (2014)

argues that this large productivity gap has been caused by two main factors, firstly the larger than expected initial fall in the productivity growth rate, and secondly the length of time for which productivity growth rates were below pre-crisis trend. The Productivity Puzzle is especially unusual when the performance of the UK is compared to similar countries over the same time period (Weale (2014)). In 2014 the UK had a productivity gap of roughly 14% compared to a G7 average of around 7% (ONS (2016*a*)).

In this section I will provide a review of the literature on the UK Productivity Puzzle, in order to provide further motivation for Chapter 3, as well as the application in Chapter 4. Two main explanations have been put forward for the size and increasing nature of the UK productivity shortfall: First, Disney *et al.* (2013) and others argue that the Productivity Puzzle is not in fact as severe as it initially appears and the explanation for this is based upon possible measurement errors in the calculation of GDP/ output, examined in Section 2.5.2. Second, Barnett *et al.* (2014) and others highlight the importance of non-cyclical factors specific to the UK and to the Great Recession, causing a prolonged stagnation in UK productivity, examined in Section 2.5.3. Section 2.5.4 summarises the literature on the Productivity Puzzle, and highlights areas for future research. Note that there is also a branch of literature that examined the unusually large size of the initial fall in UK productivity, explaining this fall through a combination of labour hoarding (see Patterson (2012), Miles (2012), Crawford *et al.* (2013), Martin and Rowthorn (2012) and Martin and Rowthorn (2013)) and 'thin market externalities' (see Goodridge *et al.* (2013*a*), Goodridge *et al.* (2013*b*), King and Millard (2014) and McCafferty (2013)). However, the unusually large size of the initial fall in UK productivity has been fully explained through these two branches of literature, and cannot contribute to our understanding of the longer term stagnation in UK productivity, therefore a more comprehensive review of this literature is not presented.

2.5.2 Impact of Measurement Errors

The first possible explanation for the UK Productivity Puzzle is that GDP/output and the labour supply in the UK may have been inaccurately measured either prior to or after the Great Recession. These inaccuracies in the measurement of productivity could have caused the Productivity Puzzle to appear more severe than it actually was. Patterson (2012) estimates the upper limit of 1% on revisions to GDP, supported by the evidence of Grice (2012), who highlighted two studies by the ONS (Brown *et al.* (2009) and Walker *et al.* (2012)), which have found no evidence of significant bias in GDP figures, and no evidence that readjustments are likely to have any significant impact on the Productivity Puzzle. Disney *et al.* (2013) examined the difficulties arising from the measurement of online trade and spending on new business acquisition, and conclude that measurement errors in these sectors caused a substantial proportion of the productivity gap in the early stages of the recession. Barnett *et al.* (2014) examine the measurement error associated with intangible investments as well as the impact of upwards revisions to GDP figures. They conclude that these, when combined with inaccuracies in the measurement of labour supply can account for up to 4% of the productivity gap. Finally, Bryson and Forth (2015) examined the impact of declining output in the North Sea Oil and Gas sector since 2000. They claim that although the output of the North Sea Oil and Gas sector has been declining since approximately 2000 the extent of this fall has not been accurately measured in official GDP figures. They conclude that the figures overstate the pre-crisis GDP growth trend, and so the pre-crisis productivity growth trend, although not to a significant degree. Therefore, even once measurement errors have been accounted for, a substantial portion of the shortfall in UK productivity remains to be explained, through non-cyclical UK/Great Recession specific factors.

2.5.3 Non-Cyclical Factors

Even after measurement errors are accounted for in explaining the UK Productivity Puzzle a substantial portion of the productivity gap remains to be explained. The explanations for the Productivity Puzzle based on non-cyclical factors are all focussed on features that are particular to either the Great Recession, the UK or a combination of the two. These explanations can be divided into several main categories: First, studies that examine the behaviour of the UK labour market, second, studies that examine impact of the fall in credit supply and other financial factors, third, studies that examine the interactions between the labour market and financial factor, fourth, studies that examine the impact of increased firm survival, and finally other non-cyclical explanations.

The first non-cyclical explanation for the UK Productivity Puzzle examined the impact of changes in the labour supply in the UK after the Great Recession. Blundell *et al.* (2014) analysed the impact of government policy changes and reductions in the average wealth of households, and showed that both of these led to increases in the labour supply during and after the Great Recession. Pessoa and Van Reenen (2014) showed that increased labour flexibility enabled firms to decrease their variable cost of labour. This allowed firms to increase their levels of labour at constant cost, which caused the productivity level to fall. Gregg *et al.* (2014) expanded this analysis to examine the impact of increased wage flexibility, and showed that the increased wage flexibility allowed firms to decrease their cost of labour, and so, to increase their labour supply relative to their supply of capital, which in turn reduced their productivity. The labour supply also increased as a result of increased migration, as shown by Bell and Eiser (2015). The increased labour supply was also combined with decreases in the efficiency of the allocation of labour after the Great Recession. Patterson *et al.* (2016) showed that impaired reallocation of labour after the Great Recession contributed significantly to the stagnation in UK productivity.

The second non-cyclical explanation for the UK Productivity Puzzle examined the impact of falls in the supply of credit and other financial factors. Oulton and Sebastia-Barriel (2013) examined the combination of reduced credit supplies and impaired capital reallocation and estimated that between them they caused a permanent fall in productivity growth of between 0.84% and 1.1%. Corry *et al.*

(2011) examined the decrease in the supply of credit in the context of increased bank capital requirements and also concluded that the decreased credit supply had impaired productivity growth in the UK. The increased formal capital requirements were exacerbated by decreased appetites for risk in financial institutions, according to Broadbent (2012). The formal increased credit requirements and decreased risk appetites were brought together by Franklin *et al.* (2015), who concluded that falls in the credit supply can account for between 5-8% of the UK productivity gap. The credit supply channel was extended further by Riley *et al.* (2014) and Riley *et al.* (2015), who examined the impact of impaired credit reallocation and bank dependency on the credit supply effect. They found that both impaired credit reallocation and increased bank dependency significantly decreased UK productivity growth.

The third non-cyclical explanation for the UK Productivity puzzle examines the interactions between the previous two explanations, i.e. the interactions between the labour market and the supply of credit. Sargent (2013) show that changes in the capital to labour ratio account for a significant proportion of the UK productivity puzzle, supported by Pessoa and Van Reenen (2014). Pessoa and Van Reenen (2014) examined the impact of increased uncertainty on the relative costs and benefits of capital and labour, and showed that the increased uncertainty resulting from the Great Recession led to falls in the capital to labour ratio, and thus productivity. The changes in factor utilisation were also observed by Goodridge *et al.* (2018), who conclude that such changes in factor utilisation could account for around 17% of the UK Productivity Puzzle.

The fourth non-cyclical explanation for the UK Productivity Puzzle is an increase in firm survival rates among less productive firms. Arrowsmith *et al.* (2013) examined bank forbearance after the Great Recession and found that this forbearance had a small but significant effect on productivity, due to increased firm survival among less productive firms. The increased firm survival among less productive firms was also observed by Barnett *et al.* (2014), Ellman (2015) and

Harris and Moffat (2016). Barnett *et al.* (2014) explain this survival through a combination of reductions in debt servicing costs, and increased HMRC forbearance while Ellman (2015) examined the impact of decreases in wage costs. Harris and Moffat (2016) show that, after the Great Recession, the empirical link between firm level productivity and firm survival weakened considerably, although they put forward no direct explanations in their paper.

The final non-cyclical explanations for the productivity puzzle examine the sector specific nature of the puzzle, and the impact of reduced investment in R&D. McCafferty (2014) claim that the Oil and Gas sector makes up a large proportion of the puzzle, a view supported by Goodridge *et al.* (2018), who also highlighted the importance of the Financial Services sector, and the possible impact of post Great Recession de-leveraging on measured productivity. The impact of reduced investment in R&D has been studied in the context of government R&D investment by Valero and Roland (2015), and in a more general context by Millard and Nicolae (2014). Both these papers find that reduced investment in R&D after the Great Recession may have led to decreased productivity growth, due to a slower growth in technology and innovation.

2.5.4 Conclusion

In section 2.5.2 we saw that measurement errors in UK output and labour supply may have had a small but significant effect on UK productivity, and in section 2.5.3 we saw that a large proportion of the non-cyclical stagnation in productivity can be explained. However, there remains a substantial portion of the stagnation in UK productivity that is unexplained, and so other possible causes for the productivity puzzle must be sought. Barnett *et al.* (2014) estimated that of a productivity gap of 16% at the time , 4% can be explained by measurement errors, less than 1% can be explained by cyclical factors and between 6% and 9% can be explained by non-cyclical factors, leaving between 5% and 9% still to be explained by other factors.

One notable area for future research is to examine the impact of the changes in international trade since the Great Recession have had on individual firms and aggregate productivity levels. Bems *et al.* (2013) showed that after the Great Recession there was a large decrease in overall levels of international trade, this in turn could have reduced UK productivity growth through a combination of a reduction in the opportunities for learning-by-exporting, as well as by decreased levels of competition from international competitors, which might have allowed unproductive firms to survive. This decrease could also have reversed the previous beneficial effects of globalisation, particularly in the services sector, according to Sentance (2015). The impact of globalisation on productivity growth in the services sector was significant in the years leading up the Great Recession. The fall in this after the crisis led to falls in productivity growth from decreased competition, and increased inefficiencies in the movement of credit.

Additionally, as highlighted in section 2.3, it is possible for changes in the origin and destination of trade to have an impact on productivity. It can also be seen that the UK has been exporting an increasingly small proportion of its trade to the European Union. (See ONS (2016*b*)). This may have allowed less competitive (less productive) firms to shelter behind the implicit increase in trade barriers derived from increased levels of trade with areas with barriers to trade and decreased trade with areas with no barriers. Given that this trend of increasing proportional trade with the rest of the world started after the Great Recession, reversing the previous trend, this may offer an explanation of part of the Productivity Puzzle. I explore this possible effect on UK Productivity in Chapter 3.

2.6 Conclusions

The literature reviewed for the purpose of this thesis discussed four main topics. The first topic is the empirical examination of the possible effect of the level of productivity and changes in productivity on the flows of international trade. The second topic is the empirical examination of the possible effect of international trade on productivity at both a macroeconomic and microeconomic level. The third topic is theoretical models of international trade and productivity that seek to incorporate findings from both of the first two topics into their model. The final topic is explanations for the UK Productivity Puzzle, divided into those examining measurement errors, cyclical explanations and non-cyclical explanations.

Through the review of the literature on each of these four topics, many significant gaps in the existing literature have emerged, of which I seek to address four in this thesis. First, although there is conclusive evidence that increased import volumes lead to increased productivity, there has been no examination thus far of the impact of changes in the origin of imports, once import volumes are accounted for. Second, although there has been much examination of the role of trading firms in driving the response of the economy to macroeconomic shocks in theoretical models of trade and productivity, there has thus far been very little examination of the role that non-trading firms play in driving this response. Given that such firms are both the least productive and most numerous type of firms (88% of UK firms according to the ONS), the response of these firms is likely to play a key role in driving the response of productivity and other macroeconomic variables to shocks. Third, although there has been much examination of whether Ricardian Trade Theory is empirically valid, there has thus far been no examination of the extent to which differences in relative productivity levels can explain relative bilateral flows of international trade, and thus the extent to which these flows are driven by Ricardian Comparative Advantage. Fourth, although many explanations have been put forward for the UK Productivity Puzzle, a significant portion of the shortfall in UK productivity remains unexplained. Thus far there has been no examination of the role that changes in international trade may have played in driving some part of the weakness in UK productivity, which I seek to also address in Chapter 3.

Chapter 3

The Impact of Changes in Import Origin on UK Productivity

3.1 Introduction

Barriers to imports are an important factor in determining the impact of international trade on a country's level of productivity. Nickell (1996) shows that changes in competition faced by domestic firms impact a country's level of productivity. Such changes in competition faced by domestic firms can appear following changes in average per-unit barriers to trade resulting from changes in trade barriers, which as Melitz (2003) shows, impact a country's level of productivity. However, barriers to trade do not always need to change for average per-unit barriers to trade to impact a country's level of productivity, as this can also change when a country changes its proportion of imports among trading partners with dissimilar barriers to trade, but, as we show in section 3.2, any changes in import origin have to be caused by a driver that does not directly impact domestic competition in order that the specific impact of the change in import origin can be isolated.

In this chapter we examine the extent to which changes in the origin of a country's imports can impact labour productivity, by analysing the link between the import share, defined as percentage of imports from a region in total imports, and aggregate labour productivity, for the case of the United Kingdom, for the period 1990-2015, for both goods and services. In the United Kingdom, starting in 2007 labour productivity fell considerably, especially during the Great Recession (2008-2009), and the growth rate of productivity after 2009 stagnated compared with its pre-crisis growth rate. After a larger than normal fall in the level of productivity (6% compared to an average of 1.5% for the 4 previous UK recessions (Barnett *et al.* (2014)), the subsequent prolonged stagnation in productivity was so large that, in 2017 Q4, UK labour productivity was 16% lower than a continuation of its pre-crisis trend would predict. This drop in productivity is unusual in the context of previous recessions, where productivity recovered quickly, and also in the context of the worldwide recovery in productivity. Indeed, after the Great Recession, productivity took 26 quarters to return to its pre-recession level, compared with an average of seven quarters for the previous four UK recessions (Barnett *et al.* (2014)). In 2015, according to the ONS, the G7, excluding the United Kingdom, were approximately 18% more productive than the United Kingdom, compared with around 3% in 2007. This unusual and largely unexplained nature of the stagnation in UK productivity is referred to as the UK Productivity Puzzle. Moreover, the drop in UK productivity in both goods and services sectors especially during the Great Recession was preceded by a significant fall in the proportion of UK imports originating in the European Union in both sectors.

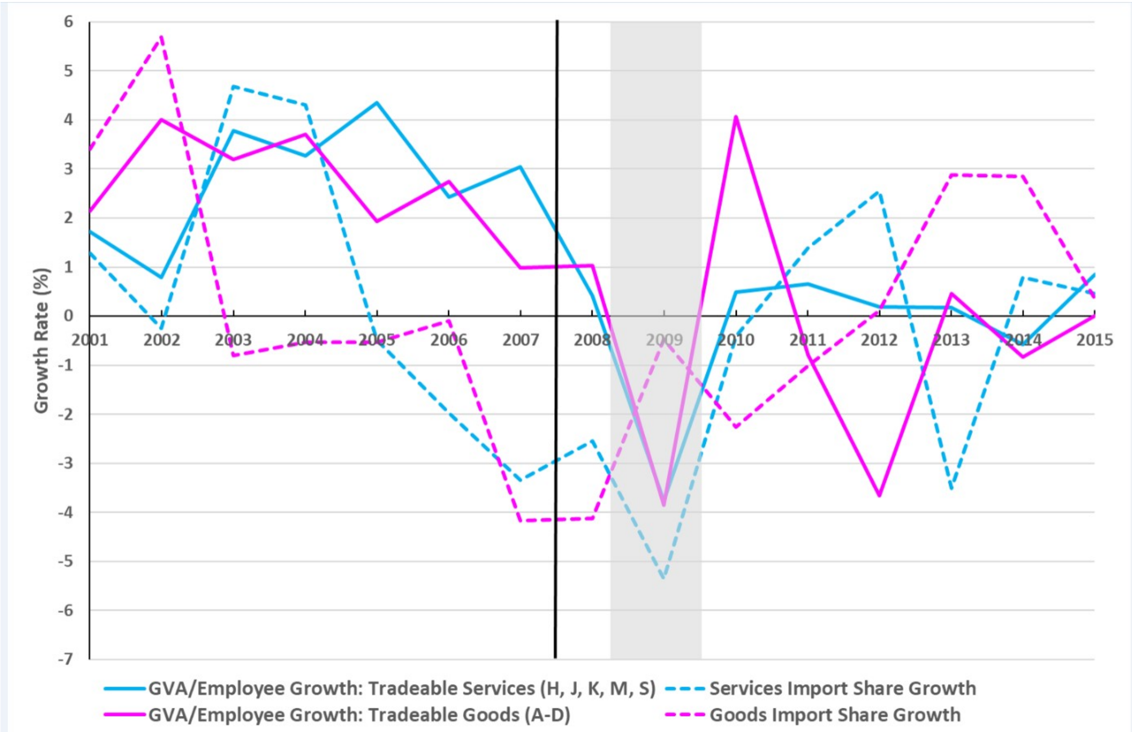
This chapter seeks to contribute to two strands of literature. The first strand comprises the well documented impact of (changes in) trade/imports on productivity. Increased total trade volume leads to increased competition resulting in increased productivity growth. Macdonald (1994), Hung *et al.* (2004), Bernard *et al.* (2006*a*) and Bloom *et al.* (2016) show that there is a positive and significant relationship between the volume of imports and productivity. In these papers, higher volumes of imports following reductions in the level of barriers to imports (due to trade liberalisation) lead to more competition in the domestic market, inducing higher productivity growth. Unlike these studies, we examine the impact of (changes) in imports on labour productivity when there are no changes in the level of barriers to imports, but average per unit barriers to imports change as a result of shifts in the origin of imports between trading partners with dissimilar barriers to trade. A related strand of literature is Schmitz (2005), Chaney (2008), Melitz and Ottaviano (2008) and Eslava *et al.* (2013), which examines the impact of changes in per-unit barriers to trade on productivity, and which provide the theoretical background mechanism for the question addressed here.

The second strand of literature explores various explanations put forward for the UK Productivity Puzzle. The focus of this literature is on explaining the subsequent stagnation in productivity, which suggests that the underlying factors behind the weakness in productivity are more structural in nature (more persistent causes related to the financial crisis). Thus far, a number of explanations have been put forward. Changes in the labour supply in the UK after the Great Recession was first put forward as a non-cyclical explanation for the UK Productivity Puzzle (see for example Blundell *et al.* (2014), Pessoa and Van Reenen (2014), Gregg *et al.* (2014), Bell and Eiser (2015), and Patterson *et al.* (2016)), followed by the reduction in the supply of credit seen since the Great Recession and other financial factors (see for example Oulton and Sebastia-Barriel (2013), Corry *et al.* (2011), Broadbent (2012), Franklin *et al.* (2015), Riley *et al.* (2014) and Riley *et al.* (2015), while papers such as Sargent (2013) and Pessoa and Van Reenen (2014) suggest that the interactions between the previous two explanations, namely the interactions between the labour market and the supply of credit, could also be considered a further explanation for this puzzle. Another explanation for the stagnation in UK productivity explored in this literature is that of the increase in firm survival rates among less productive firms first observed by Barnett *et al.* (2014) and then explored by Arrowsmith *et al.* (2013), Ellman (2015) and Harris and Moffat (2016). Sector specific explanations by McCafferty (2014) and Bryson and Forth (2015) examining the oil and gas sector which makes up a large proportion of the puzzle, and the impact of reduced investment in R&D (Valero and Roland (2015) and Millard and Nicolae (2014)) have also been put forward as explanations for the puzzle.

However, despite all this important body of work, a significant proportion of the puzzle remains unexplained, according to Barnett *et al.* (2014), and this is where this chapter seeks to contribute. We attempt to provide a complementary explanation to the ones already presented in the literature by providing yet another possible explanation which could contribute to explaining the still unexplained part of the puzzle/productivity shortfall. None of the explanations presented so far examine the effect of changes in international trade, more specific in UK imports, on UK productivity in an attempt to explain this puzzle. Such a change in imports could affect UK productivity in two ways. First, Bems *et al.* (2013) showed that after the Great Recession there was a large decrease in overall levels of international trade (the great trade collapse), which in turn could have reduced UK productivity growth through a combination of a reduction in the opportunities for learning-by-exporting and lower levels of competition from international competitors, which might have allowed unproductive firms to survive, possibly reversing the beneficial effects of globalisation, particularly in the services sector, according to Sentance (2015). However, after the crisis ended trade picked up while UK productivity stagnated, showing that the great trade collapse could not explain the stagnation in UK productivity. The second way in which trade could have affected UK productivity is through changes in the origin of UK imports, which may have caused changes in average per-unit barriers to trade which, as Melitz (2003) shows, impact a country's level of productivity. To the best of our knowledge the impact of import origin changes on UK productivity has not been addressed so far in this literature.

To explore this, Figure 3.1 plots the growth rate of gross value added (GVA) per employee in tradable goods (the pink solid line), defined as agriculture, forestry and fishing, mining and quarrying, manufacturing (ONS SIC07 codes A-D), and the growth rate of the import share for the goods sector (the pink dotted line), defined as the percentage of EU goods imports in total UK goods imports. It also plots the growth rate of GVA per employee in tradable services (the blue solid line) defined as transportation and storage, information and communication, financial and insurance, professional, scientific and technical, and other services (ONS SIC07 codes H, J, K, M and S), and the growth rate of the tradable services import share (the blue dotted line), defined as the percentage of EU services imports in total UK service imports.

Figure 3.1: UK Import Share from the European Union and UK Productivity Growth for Tradeable Goods and Services



According to the literature, the time lag for changes in trade to impact productivity is about one year. (See, for example, Cameron *et al.* (2005) and Macdonald (1994).) Once this time lag is accounted for, there appears to be a weak correlation between the growth rate of tradable goods productivity and the growth rate of the goods import share, as shown by the pink dotted and solid lines in Figure 3.1 (correlation coefficient = 0.34). There appears to be a much stronger correlation between the growth rate of tradable services productivity and the growth rate of the tradable services import share shown by the blue dotted and solid lines, once the one-year time lag is accounted for (correlation coefficient = 0.52). The question that arises is how can this apparent link between the import share and labour productivity be explained?

Since the United Kingdom joined the European Union in 1972, there have been no tariff and limited non-tariff barriers to trade for UK imports from the European Union[1], whereas there have been significant tariff and non-tariff barriers to UK imports from the rest of the world in both goods and services[2]. A fall in the volume of imports from the European Union relative to the rest of the world will lead to an increase in the average per-unit barrier to UK imports. However, this increase in the average per-unit barrier to UK imports will not necessarily lead to an increase in the number of firms with low productivity and thus induce a reduction in average productivity as predicted by Melitz (2003), as competition might not necessarily change.

To illustrate this, assume two hypothetical worlds: one world in which a country imports 60% of its goods from countries with which it has free trade agreements, and 40% from countries with which it does not have free trade agreements, and another world in which the same country imports 40% imports of its goods from countries with which it has a free trade agreement, and 60% from countries with which it does not have free trade agreements. The importing country will face more competition from imports in the first hypothetical world than in the second one due to lower average per-unit barriers to trade. In the case in which the driver of the change in import share is not directly linked to competition in the importing country (such as, for example, a shift in tastes/preferences), we expect competition from imports to change, leading, as Nickell (1996) argues, to a change in productivity. However, if the move from the one hypothetical world is caused by a driver that is directly linked to competition in the importing country, such as would be the case if the move were driven by changes in the relative price , the effect of the change in the import share on competition, and thus productivity, cannot be identified. In this chapter we examine the impact of shifts in the origin

[1] See 'Treaty on the Functioning of the European Union (Part 3, Title II)'.
[2] See https://www.gov.uk/goods-sent-from-abroad/overview.

of imports where the driver of the change in import share is not directly linked to competition and are therefore expected to lead to changes in productivity.

Given the low correlation between the growth rate of productivity and the growth rate of the import share seen in the case of tradable goods, we expect the change in the UK import share for goods to have been caused by a driver that is directly linked to competition in the UK, rather than an indirect cause such as a shift in preferences. We show that this was the case given China's accession to the World Trade Organisation (WTO) in 2001 and the ensuing period of high relative productivity growth in China when compared to the European Union. We would therefore expect no causal link from the UK goods import share growth to productivity growth in tradable goods.

However, given that there were no significant changes in UK barriers to services imports from outside the European Union and lower barriers to services imports from the European Union after the Nice treaty in 2001 and the Lisbon treaty in 2007[3], then, absent significant changes in relative productivity or exchange rates, we would expect any change in the UK import share to have been driven by changes in tastes, which are not directly linked to competition in the UK, rather than by a driver such as changes in relative prices, which would be directly linked to UK competition. We would therefore expect to identify a link between productivity growth and the growth of the UK import share for services. Therefore, in this chapter we investigate whether changes in the UK import share from the European Union induced changes in UK labour productivity for tradable services. Ideally, we would analyse the changes in import share and productivity at firm level, given the theoretical framework we employ. However, we analyse productivity solely at the macroeconomic level, due to the lack of comprehensive firm-level data on competition and engagement in international trade for the United Kingdom[4].

[3]See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A12001C%2FTXT for details on the Treaty of Nice and http://www.lisbon-treaty.org/ for details on the Lisbon Treaty.

[4]Although such firm-level data for goods is available for the UK from HMRC, there is no such firm-level data in services available which we could use for our analysis.

We find that there is Granger causality from the UK import share to UK labour productivity in tradable services. Given this Granger causality and the exogeneity of the shift in the import share, we argue that there is a causal relationship from the UK import share to UK labour productivity in the tradable services sector. Given this causal relationship, and the fact that according to the ONS in 2015 approximately 28% of UK GDP consists of tradable services, we argue that the decreases in the proportion of UK services imports from the EU from 2006 to 2015 led to decreases in UK productivity and therefore could further contribute to our understanding of the UK Productivity Puzzle.

Outline of the Chapter

The chapter is organized as follows: in Section 3.2 we outline the theoretical link between the import share and productivity. In Section 3.3 we present our macroeconomic empirical analysis and an application of our findings to the UK Productivity Puzzle. Section 3.4 concludes with a summary of findings and suggestions for future research.

3.2 The Link Between the Import Share and Labour Productivity for the United Kingdom

In this section we outline the theoretical link between the import share and productivity distinguishing between drivers of the import share that are directly and indirectly linked to competition in the UK. We then present and discuss the different sources of change in the import share for goods and services separately for the United Kingdom for the period 2000-2015. We then assess whether the drivers of the import share changes for goods and services, were directly or indirectly linked to UK competition and thus UK productivity, which enables us to characterise the link between changes in the origin of imports and productivity.

3.2.1 The Theoretical Link Between Import Share and Labour Productivity

Understanding the link between the import share and productivity helps us identify if changes in the origin of imports could be a driver of productivity. If a country changes its proportion of imports between trading partners with dissimilar barriers to trade (captured in this chapter by the import share), this results in new average per-unit barriers to imports. Nickell (1996) argues that changes in the competition faced by domestic firms have an effect on a country's level of productivity, and as Melitz (2003) shows, changes in competition can be induced by changes in average per-unit barriers to trade. The import share can change as a result of: changes in preferences and/or tastes, or changes in the relative price of imports from different trading partners. The question that arises is to what extent changes in tastes or in the relative price directly affect productivity and therefore, how much of the indirect effect (through changes in the import share) of the changes in tastes or relative prices can be offset by the direct effect they might have on productivity?

A change in tastes, which as Barten (1964) shows will affect consumer demand, will lead to changes in the import share, which, through the mechanism above, will lead to changes in productivity. For example, if UK tastes shift such that imports from the rest of the world are in greater demand relative to the imports from the European Union, this will lead to a decline in the import share from the European Union, leading to new, higher average per-unit barriers to imports. Higher, average per-unit barriers to imports will decrease competition in the domestic market, and as Melitz (2003) shows, lower competition in the domestic market induces changes in the number of firms with lower productivity, allowing unproductive firms to enter the market leading to lower average productivity. The change in tastes has no direct impact on competition; therefore, we can conclude that in this case, the driver of change in import share only indirectly impacts productivity. Thus, in this case we would expect changes in the import share to cause changes in productivity. However, if the change in the import share is driven by a change in the relative price, the impact on productivity is more complex. A change in the relative price can be driven by: a change in relative productivity, a change in the relative exchange rates, or a change in the relative tariff and non-tariff barriers to imports.

For example, a decrease in the relative price of imports from the rest of the world, if driven by relative productivity or relative exchange rate changes, will lead UK consumers to switch from EU goods to the cheaper rest of the world goods, thus decreasing the import share and increasing the average per-unit barriers to imports. In the absence of a direct link from the relative price to productivity, domestic productivity would decrease. However, the relative price and productivity are also directly linked through competition. In this example, the decrease in the relative price will directly lead to an increase in productivity in the domestic country through an increase in competition in the domestic market, as domestic producers are forced to compete with new, lower import prices. Therefore, even though the import share decreased and thus per-unit barriers to imports increased, productivity increases due to the direct competition effects.

In the case where the change in the relative price is driven by a change in the relative tariff and non-tariff barriers to imports, then the link between changes in the import share and productivity disappears. For example, in the case where a decrease in the relative price of imports from the rest of the world is driven by a decrease in barriers to imports from the rest of the world, then the average per-unit barriers to trade will not increase as the import share decreases, but will instead decrease, thus, increasing competition and productivity on the domestic market. Therefore, since changes in relative price directly impact productivity, we cannot isolate any effect of changes in the import share on productivity in this case.

3.2.2 Sources of Changes in the UK Import Share for the Goods and Services Sectors

As we have seen in Figure 3.1, there are different degrees of correlation between the growth rate of tradeable goods productivity and the growth rate of the goods import share, and the growth rate of tradeable services productivity and the growth rate of the tradeable services import share, once the one-year time lag is accounted for, with the latter stronger than the former. Therefore, for the analysis conducted here, we outline separately the evolution of UK imports of goods and services from trading partners with dissimilar barriers to trade, and the drivers of changes in the relative price of imports from 2000 to 2015.

Sources of Changes in the UK Import Share for the Goods Sector

In this section we present the evolution of the UK import share from the European Union for goods from 2000 to 2015, and the potential drivers of the changes in the price of imports from China relative to that of imports from the European Union, which led to the increase in UK goods imports from China relative to goods imports from the European Union for this period. China's accession to the WTO in 2001 and the ensuing period of high relative productivity growth in China compared to the European Union could be the main driving forces leading to a change in the UK import share for goods.

The UK import share from the European Union for goods dropped from 2002 to 2011, as a result of a significant increase in UK imports of goods from China, following China's accession to the WTO in 2001[5]. Data from the ONS Pink Book shows that between 2002 and 2011, the proportion of UK imports of goods from China increased by 176%, from 2.9% to 7.9%, while the proportion of UK imports of goods from the European Union declined by 12.9%, from 58.5% to 50.9%. Thus, overall, the ratio of UK goods imports from China to UK goods imports from the European Union increased by 216.8% over this time period, from 4.9% to 15.6%.

[5]According to our calculations based on data from the ONS Pink Book.

Next we present the potential drivers of the change in the relative price of imports from China and the European Union, in order to identify which of them led to the increase in UK goods imports from China relative to goods imports from the European Union: tariff and non-tariff barriers to trade to UK imports from China and the European Union, the relative productivity between China and the European Union, and the relative exchange rate (values of the renminbi and the euro).

Both the tariff and non-tariff barriers to UK imports from China decreased significantly following China's accession to the WTO in 2001[6]. Thus, the tariff rates and quotas on UK imports from China dropped considerably leading to a decrease in the relative price of Chinese goods. Next, an examination of World Input-Output Database (WIOD) productivity data[7] from 2002 to 2011 shows that the ratio of China's productivity in tradeable goods to EU tradeable goods productivity increased by 170.3%, from 5.7% to 14.4%. Upward *et al.* (2013) argue that the official productivity figures in Chinese tradeable goods industries may not accurately reflect the productivity of exporters, and the actual productivity of Chinese firms engaged in exporting is, in fact, much greater due to higher levels of protection from foreign competition. The increase in the relative productivity of Chinese firms would cause Chinese goods to become relatively cheaper.

The ratio of the renminbi-sterling exchange rate to the euro-sterling exchange rate increased by 14.6% over the period 2002-2011[8]. A decrease in the relative value of the Chinese yuan compared with the euro caused Chinese goods to become relatively cheaper compared with goods from the European Union. Changes in relative productivity levels, exchange rates and barriers to imports all contributed to a decrease in the relative price of Chinese goods compared to EU goods. As

[6]See Edmonds *et al.* (2008) and https://www.wto.org/english/thewto_e/acc_e/acc_e.htm
[7]See Timmer *et al.* (2015) for full details of the World Input-Output Database.
[8]See https://www.investing.com/currencies/.

presented in earlier, if a change in the import share is driven by a change in relative prices, then the effect of the change in the import share on competition and thus productivity is unidentifiable, as such a change in relative prices will also directly affect competition and thus productivity in the importing country. Therefore, given the shift in the import share for goods was driven by changes in the relative price, we would not expect to identify a causal link between productivity growth and the import share growth for tradeable goods. Thus, in our econometric analysis we do not test for causality from the import share to productivity for tradeable goods.

Sources of Changes in the UK Import Share for the Services Sector

In this section we present the evolution of the UK import share from the European Union for services from, 2000 to 2015, and the potential drivers of the relative price of imports from the United States and the European Union which led to the increase in UK services imports from the United States relative to services imports from the European Union for this period.

The UK import share from the European Union for services declined from 2004 to 2009. This decline was driven by a large increase in UK imports of services from the United States of America. Data from the ONS Pink Book shows that the proportion of UK imports of services that originated in the United States increased by 9.1% during this period, from 16.2% to 17.6%, while over the same period, the proportion of UK imports of services that originated in the European Union declined by 12.6%, from 55.7% to 48.7%. Thus, overall, between 2004 and 2009, the ratio of UK services imports originating from the United States to UK services imports originating from the European Union increased by 24.8%, from 29.1% to 36.4%.

We next outline the potential drivers of the changes in the relative price of imports from the United States and the European Union, in order to identify which of them led to the increase in UK services imports from the United States relative to services imports from the European Union: tariff and non-tariff barriers to trade to UK imports from the United States and the European Union, the relative productivity between the United States and the European Union, and the relative exchange rate (values of the US dollar and the euro).

Unlike for UK goods imports from China, there were no significant changes in either tariff or non-tariff barriers for UK services imports from the US over 2004-2009. However, after the Nice treaty in 2001 and the Lisbon treaty in 2007[9] the non-tariff barriers to trade for imports of services from the European Union decreased. Thus, US services would have become relatively more expensive over this period. As WIOD data shows, from 2004-2009, the ratio of US productivity in tradeable services to EU tradeable services increased by 7.5%, from 73.1% to 78.6%. In a similar manner to the imports of goods, the increase in the relative productivity of the United States would cause US services to become relatively cheaper. The ratio of the dollar-sterling exchange rate to the euro-sterling exchange rate increased by 12.1% over the period 2004-2009[10]. A decrease in the relative value of the US dollar compared with the euro, would cause US services to become relatively cheaper compared with services from the European Union.

Following a cheapening of the US dollar relative to the euro, US services became cheaper. Alongside this, we have seen an increase in US services productivity. However, given the decrease in non-tariff barriers to imports of services from the European Union and the resultant increase in the relative price of US services, we cannot entirely explain the change in the import share for services. It can therefore be argued that the change in the import share for services was driven, at least in part, by changes in tastes. We would therefore expect to identify a causal link from the import share for services to productivity in tradeable services in our empirical analysis.

[9]See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A12001C%2FTXT for details on the Treaty of Nice and http://www.lisbon-treaty.org/ for details on the Lisbon Treaty.

[10]See https://www.investing.com/currencies/.

Next, we present a breakdown the change in the origin of UK services imports at an industry level, in order to identify the particular industries that drove the changes in the origin of UK services imports. Using data from the World Input Output Database[11] we can calculate the percentage change in the ratio of UK imports from the USA to UK imports from the EU for each services industry. We then weight each of theses percentages by the proportion of UK imports from each industry in total UK services imports, to derive a measure of the industries that primarily drove the change in UK services import origin. Table 3.1 shows the import weighted change in the USA to EU import ratio, indexed such that the import weighted change in the USA to EU import ratio in Media activities is equal to 1.

As Table 3.1 shows, the main drivers of the changes in the origin of UK services imports are Other Service Activities, Architectural and Engineering Services, Scientific Research and Development, Telecommunications and in particular Media Activities, which accounted for almost the same proportion of the change in import origin as the other four combined. Media activities as an industry are particularly susceptible to changes in consumer tastes, as it is well known that such activities are price invariant across different origin countries. Increasing UK consumer demand for US television and cinema media is likely to have played a significant role in driving the change in the origin of services imports, and is only indirectly linked to changes in competition on the UK market through the change in the import origin. The other four primary drives of the change in the origin of UK services are all industries that are likely to be greater impacted by changes in tastes, much more so than other services industries such as financial or insurance activities. Given that the change in the UK services import share was driven by changes in tastes, which only indirectly affects UK productivity we can consider the change in import share to be exogenous to the change in productivity. Therefore, if we find evidence of Granger causality in the empirical regressions we can conclude that we have identified a causal relationship.

[11]See Timmer *et al.* (2015) for full details of the World Input-Output Database.

Table 3.1: Industry Level Drivers of the Change in the Origin of UK Services Imports

WIOD Code	Industry Name	Import Weighted Change in US/EU Import Ratio
J59t60	Media Activities	1
J61	Telecommunications	0.311
M72	Scientific Research and Development	0.272
M71	Architectural and Engineering Services	0.265
RtS	Other Service Activities	0.243
M69t70	Legal and Accounting Activities	0.055
M73	Advertising Services	0.098
O84	Public Administration and Defence	0.049
H51	Air Transport	0.045
H52	Warehousing and Transportation Support	0.028
M74t75	Other Professional Activities	0.027
K65	Insurance Services	0.018
H53	Postal and Courier Activities	0.008
T	Household Activities	-0.004
K64	Financial Services	-0.002
K66	Auxiliary Financial and Insurance Services	-0.002
G45	Wholesale Trade of Motor Vehicles	-0.009
Q	Health and Social Work	-0.009
P85	Education	-0.022
H49	Land Transport	-0.029
F	Construction	-0.032
G47	Retail Trade (except motor vehicles)	-0.037
L68	Real Estate Activities	-0.050
H50	Water Transport	-0.066
I	Accomodation and Food Service	-0.081
J62t63	IT Services	-0.092
J58	Publishing Activities	-0.198
N	Administrative Services	-0.263
G47	Wholesale Trade (except motor vehicles)	-0.296

In this chapter we investigate whether changes in the UK import share from the European Union caused changes in UK labour productivity for tradeable services. Therefore, in the next section we test for Granger causality from the import share for services to productivity in tradeable services. If we find Granger causality, given the exogeneity of the shift in the import share, we will argue that there is a causal relationship from the UK import share to UK labour productivity in the tradeable services sector.

3.3 Econometric Analysis

Given the theoretical framework in the previous section, in an ideal world, we would analyse the changes in import share and productivity at firm level. However, due to the lack of firm-level data on competition and engagement in international trade for the United Kingdom, we analyse productivity and competition changes solely at the macroeconomic level.

Our hypothesis is that a change in the origin of imports impacts labour productivity. We test this hypothesis by examining whether the change in the UK import share from the European Union for services, which as we have already argued, was driven by changes in tastes, caused changes in UK labour productivity for tradeable services, when we allow for variations in the import to GDP ratio, using a simple empirical analysis, on annual data for the years 1990-2015[12]. Econometrically, given that the driver of the change in the origin of UK imports (i.e. changes in tastes) was not directly linked to competition in the UK, we will be able to isolate the causal impact of any changes in the origin of imports on UK productivity.

3.3.1 Data

The data used to calculate UK productivity are from the UK Office for National Statistics (ONS) 'GDP (O) Low Level Aggregates 2016' and 'A01 Labour Markets Statistics Summary Data Tables 2016'. Our analysis will be conducted on data from 1990 to 2015, which is the longest possible time range for which data is available (productivity data at industry level is only available from 1990). The ONS measures productivity at sectoral level as output-per-hour and output-per-job. We would like to have examined Total Factor Productivity (TFP), which better reflects underlying productivity, rather than partly being a reflection of the level of capital employed by each worker, see, for example, Harris and Moffat (2015*a*). However, we follow the existing literature exploring the UK Productivity Puzzle, for example

[12]For completeness we run the same analysis for tradeable goods, the results of which are presented in Appendix A.4.

Barnett *et al.* (2014) and Bryson and Forth (2015)) and use gross value added (GVA) output per employee and GVA output per hour, given the lack of available data on TFP at a sectoral level.

Industry level GVA per employee figures are calculated by dividing ONS industry level GVA from Table 3: 'CVM £Million' of the ONS 'GDP (O) Low Level Aggregates 2016' by the ONS industry level workforce jobs from Table 6: 'Workforce Jobs By Industry' of the ONS 'A01 Labour Markets Statistics Summary Data Tables 2016'. We know that only productivity in the tradeable goods and tradeable services-sectors will be associated with changes in import share, thus only tradeable goods and services will be included in the measure of productivity used in the empirical analysis. Tradeable industries are defined as industries where the export/output ratio is greater than 5%[13]. The tradeable and non-tradeable categorisation is presented in Table 3.2.

To calculate the ratio of exports to output for each industry, we use data from the World Input Output Database[14]. This database contains the input-output tables for 40 countries (including all EU countries) across 35 different industries from 1995 to 2011. The data was used to compile an average export/output ratio for each industry, across the 17 years of available data. The industries in the WIOD are categorised by the EU industry classifications, which we matched to the equivalent ONS SIC07 industry classifications.

The GVA per employee figures for tradeable goods are constructed by summing the GVA and employee figures for 'Agriculture, forestry & fishing', 'Mining & quarrying' and 'Manufacturing', and then dividing the summed GVA by the total number of jobs. Similarly, for GVA-per-Employee for tradeable services we summed the GVA and jobs figures for 'Transport & storage services', 'Information

[13]This percentage was used to match the tradeable/non-tradeable industries to those in Goldstein and Officer (1979) and Melliss (1993).

[14]See Timmer *et al.* (2015) for full details of the World Input-Output Database.

Table 3.2: Tradeable/Non-Tradeable Industry by ONS SIC07 Classifications

Industry Name	ONS SIC07 Code	WIOD Code	Tradeable* (Yes/No)
Agriculture, forestry & fishing	A	A, B	Yes
Mining & quarrying	B	C	Yes
Manufacturing	C	15t37	Yes
Electricity, gas, steam & air conditioning supply	D	E	No
Water supply, sewerage, waste & remediation activities	E	E	No
Construction	F	F	No
Wholesale & retail trade; Repair of motor vehicles	G	50t52	No
Transport & storage	H	60t63	Yes**
Accommodation & food service activities	I	H	No
Information & communication	J	64	Yes
Financial & insurance activities	K	J	Yes
Real estate activities, administrative & support activities	L, N	70	No
Professional scientific & technical activities	M	71t74	Yes
Public admin & defence; Compulsory social security	O	L	No
Education	P	M	No
Human health & social work activities	Q	N	No
Arts, entertainment & recreation	R	N/A	No
Other service activities	S	O	Yes

Notes: *Defined as an export/output ratio of greater than 5%.
**Includes non-tradeable 'Inland transport', however, all other industries are tradeable.

& communication services', 'Finance & insurance services', 'Professional services' and 'Other services' and then dividing the summed GVA by the total number of jobs.

The UK import share from the European Union is calculated as the percentage of UK imports from the European Union in total UK imports. The data used to calculate this share is from the ONS Annual Pink Book, the main directory of UK trade statistics. The Pink Book provides data on import origin and export destination broken down by worldwide geographical region starting from 1988. This data is available for both goods and services; however, trade data is not available at an industry level.

The increase in the number of EU member states from 1995 to 2013 by 16 states may have resulted in jumps in the share of UK imports originating in the European Union[15]. However, data from the ONS Pink Book shows no significant change in UK imports from the European Union in 1995 and 2004, when groups of new countries joined the European Union, as most UK imports from the European Union originate in countries that were EU members prior to 1995 (Germany, France, Ireland, Spain, and Belgium). The majority of changes in the number of states acceding to the European Union were completed by 2004. The three countries that joined after 2004 (Bulgaria, Romania and Croatia) provide an extremely small proportion of UK imports[16]. The UK import to GDP ratio is defined as the percentage of UK imports in UK GDP. The data used to calculate this ratio is from the ONS Annual Pink Book and 'Gross Domestic Product: Chained Volume Measures: Seasonally Adjusted £m (ABMI) 2016'.

3.3.2 Econometric Methodology and Results

To test our hypothesis, we follow standard econometric procedure. We first establish whether the variables (log GVA per employee, log UK import share, and log import to GDP ratio for goods and services) are stationary using the Augmented Dickey-Fuller (ADF) and Phillips and Perron (1988) unit root tests. We then establish whether the series are cointegrated using the Johansen (1991) test. Finally, given that the variables are non-stationary and there is one and only one cointegrating relationship between them, we perform the test for Granger causality by fitting a Vector Error Correction Model (VECM) to the time-series variables employed for this analysis, using the Engle and Granger (1987) two-step approach. Econometric identification of a causal relationship requires both Granger

[15] Austria, Finland and Sweden in 1995, Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia in 2004, Bulgaria and Romania in 2007 and Croatia in 2013.

[16] From 2004 to 2014, on average, 86% of UK imports from the European Union are from countries that were EU members before 1995.

causality and a driver of changes in the independent variable that is exogenous to changes in the dependent variable. Thus, we can consider the causal relationship to be identified in the empirical regressions if we find evidence in favour of Granger causality in our empirical regressions, given that we have already shown that changes in the import share in services were exogenous to changes in productivity. The time series variables are as follows: PROD_TS, IS_S and IM_S, where PROD_TS denotes the natural logarithm of UK productivity in tradeable services, IS_S denotes the natural logarithm of the European Union's share of UK imports in services, and IM_S denotes the natural logarithm of UK import to GDP ratio in services[17].

Unit Root Tests

The results of the unit root test for services data, according to both the ADF and the Phillips-Perron tests show that all variables are non-stationary at the 5% significance level, and that the first difference of these variables are stationary at the 5% significance level, as reported in the Table A1 in Appendix A.1. We therefore confirm that all the time series are integrated processes of order one, I(1), and proceed with cointegration tests.

Cointegration Tests

Given that all the time series are I(1), some of these time series may exhibit long-run cointegrating relationships with each other. To test for the presence of long-run cointegrating relationships we employ the Johansen (1991) test. The results of the Johansen (1991) test show that there is one and only one cointegrating relationship for services, as presented in Table A2 in Appendix A.2. Given this result, we next use the Engle and Granger (1987) two-step approach to estimate the VECM, rather than the Johansen (1991) methodology, to avoid the larger loss of degrees of freedom associated with the Johansen (1991) methodology.

[17]For the analysis of tradeable goods presented in Appendix A.4, the time series variables are PROD_TG, IS_G and IM_G where PROD_TG denotes the natural logarithm of UK productivity in tradeable goods, IS_G denotes the natural logarithm of the European Union's share of UK imports in goods, and IM_G denotes the natural logarithm of UK import to GDP ratio in goods.

The use of the Engle and Granger (1987) two-step approach to VECM estimation, in our case requires the assumption that there exists a long-run relationship between productivity and at least one of the right hand side variables. If no such long-run relationship exists, then the estimated coefficients in our VECM below will be spurious. The existing literature shows that there is a long-run relationship between productivity and the import to GDP ratio, for example, Macdonald (1994), Bernard *et al.* (2006*b*) and Bloom *et al.* (2016), therefore we can be confident that the assumption necessary for the Engle and Granger (1987) two-step approach holds[18].

Vector Error Correction Model

Our Johansen (1991) test results for cointegration suggest that our three services time-series variables have a cointegration rank of one. The optimal lag length was identified using the Schwartz Information Criterion and the Hannan-Quinn Criterion, and was found under both these criteria to be one (see Appendix A.3 for results). The first step in the Engle and Granger (1987) approach to VECMs is the estimation of the long-run relationship:

$$\begin{aligned} PROD\_TS_t = \underset{(0.3631)^{***}}{8.4057} + \underset{(0.2226)^{***}}{0.9982} IS\_S_t + \underset{(0.03765)^{***}}{0.9877} IM\_S_t + \theta S_t. \end{aligned} \tag{3.3.1}$$

Rearranging, we obtain the estimated residual equation:

$$\widehat{\theta S_t} = PROD\_TS_t - 8.4057 - 0.9982 IS\_S_t - 0.9877.IM\_S_t \tag{3.3.2}$$

We run the Cointegration ADF (CADF) and Phillips-Perron (1988) tests on the time series of the estimated long-run relationship residual ($\widehat{\theta S_{t-1}}$) to determine

[18]Peseran and Shin (2002) showed that, in a VECM, the system of cointegrating equations is exactly identified if the number of restrictions on the cointegrating equations is exactly equal to the number of cointegrating vectors squared. If there are more restrictions than the number of cointegrating vectors squared, then the system is over-identified, whereas if there are fewer restrictions than the number of cointegrating vectors squared, the system is under-identified. In our case, the restriction on the cointegrating equation exactly identifies the system, as the number of restrictions is equal to the number of cointegrating vectors squared, ie, one, and thus we next proceed to estimating the full VECM.

whether these deviations from long-run equilibrium are stationary. If they are, then we can argue that equation (1) estimates a long-run cointegrating relationship for services. The results of the CADF and Phillips-Perron tests are presented in Table 3.3:

Table 3.3: CADF and Phillips-Perron Unit Root Test Results

Variable	CADF Test	Phillips-Perron Test
$\widehat{\theta S_{t-1}}$	-3.351** [0]	-3.351**

Notes: The figures in brackets denote the optimal lag length, determined using the Schwarz Information Criteria. Significant at or below ** 1% and * 5% significance.

Given that the optimal lag length, determined using the SIC is zero for services, the CADF and the Phillips-Perron tests are identical. We find that $\widehat{\theta S_{t-1}}$ is stationary at the 1% significance level. These results mean that the long-run relationship estimated in equation (3.3.1) is the long-run cointegrating relationship for services. We next proceed to undertake the second step of the two-step Engle and Granger (1987) approach, namely the estimation of the full VECM. The estimated VECM for tradeable services is as follows:

$$\Delta PROD\_TS_t = \eta_1 + \delta_{11}\widehat{\theta S_{t-1}} + \delta_{21}\Delta PROD\_TS_{t-1} + \delta_{31}\Delta IS\_S_{t-1} + \delta_{41}\Delta IM\_S_{t-1} + \epsilon_{1t}, \tag{3.3.3}$$

$$\Delta IS\_S_t = \eta_2 + \delta_{12}\widehat{\theta S_{t-1}} + \delta_{22}\Delta PROD\_TS_{t-1} + \delta_{32}\Delta IS\_S_{t-1} + \delta_{42}\Delta IM\_S_{t-1} + \epsilon_{2t}, \tag{3.3.4}$$

$$\Delta IM\_S_t = \eta_3 + \delta_{13}\widehat{\theta S_{t-1}} + \delta_{23}\Delta PROD\_TS_{t-1} + \delta_{33}\Delta IS\_S_{t-1} + \delta_{43}\Delta IM\_S_{t-1} + \epsilon_{3t}. \tag{3.3.5}$$

The estimated models and causality tests are presented in Table 3.4, where equations (3.3.3), (3.3.4) and (3.3.5) in the table present the estimated coefficients and causality tests for equations (3.3.3), (3.3.4) and (3.3.5) respectively.

In a VECM model, according to Granger (1988), causality can occur in three

Table 3.4: Services VECM Results

Equation	Dependent Variable	$\widehat{\theta S_{t-1}}$	$\Delta PROD\_TS_{t-1}$	ΔIS_S_{t-1}	ΔIM_S_{t-1}	F_1	F_2	Constant
(3.3.3)	$\Delta PROD\_TS_t$	-0.3675**	0.6137***	0.2673	-0.1853	4.0743**	2.0639	0.01090*
		(-0.1609)	(-0.2065)	(-0.2318)	(-0.2091)			(0.005703)
(3.3.4)	ΔIS_S_t	0.09459	0.2364	-0.1094	-0.2067	1.5114	1.1101	1.999×10^{-3}
		(-0.1738)	(-0.1983)	(-0.2226)	(-0.2009)			(0.005478)
(3.3.5)	ΔIM_S_t	0.3648**	0.04359	0.6509***	0.1947	3.2328*	5.0193**	0.01446**
		(-0.1720)	(-0.1963)	(-0.2204)	(-0.1988)			(0.005422)

Notes: The figures in brackets are the standard errors. Significant at or below *** 1%, ** 5% and *10% significance.

different ways: long-run, short run and overall Granger causality. Long-run causality is shown by the coefficients on the estimated long-run residuals ($\widehat{\theta S_{t-1}}$). The impact of these estimated long-run residuals on the dependent variables captures the extent to which the dependent variable is out of equilibrium and thus, according to Granger (1988), can be interpreted as long-run causality. Short-run causality in a VECM is shown by the lagged differences of the independent variables. It is suggested by Granger (1988) that the impact of the independent lagged differenced variables on the dependent variables captures the short-run changes in the model, and thus can be interpreted as short-run causality. Finally, Granger causality is shown by the joint significance of the estimated long-run residuals and the lagged differences of the independent variables. If the coefficient of a lagged differenced independent variable is jointly significant with the coefficient on the estimated long-run residuals, then we can argue that this independent variable Granger causes the dependent variable. Toda and Phillips (1994) examine the asymptotics for causality tests, in both a VAR and VECM framework, and conclude that these three forms of causality are robust in a VECM framework.

The results of the estimated VECM for tradeable services presented in Table 3.4, shows that the coefficient on the estimated long-run residuals $\widehat{\theta S_{t-1}}$ is strongly significant in equation (3.3.3) and in equation (3.3.5). This implies that, in tradeable services, long-run causality runs from the EU share of UK imports and from the import to GDP ratio to productivity, and from productivity and the EU share of UK imports to the import to GDP ratio, but does not run from productivity and the import to GDP ratio to the EU share of UK imports. The estimation results for equation (3.3.3) show that in the short run there is no causality between either the EU share of UK imports or the import to GDP ratio and productivity, and that the import to GDP ratio does not Granger cause productivity. However, the EU share of UK imports does Granger cause productivity in tradeable services. The estimation results for equation (3.3.4) show that there is no short run or Granger causality from either productivity or the import to GDP ratio to the EU share of UK imports in tradeable services. Finally, the estimation results for equation (3.3.5) show that although there is no short-run causality from productivity to the import to GDP ratio, there is short-run causality from the EU share of UK imports to the import to GDP ratio. Additionally, the results of the joint F tests show that productivity Granger causes the import to GDP ratio and the EU share of UK imports Granger causes the import to GDP ratio.

We have argued in the previous section that the change in the UK import share for services was exogenously driven by a change in tastes. Hence, since our results show that the EU share of UK imports Granger causes productivity in tradable services, we argue that there is a causal link from the EU share of UK imports to productivity in tradable services. Therefore, we conclude that in the United Kingdom, for the period analysed, a decrease in competition from imports in tradable services driven by an exogenous change in the origin of imports, caused a decrease in productivity in tradable services, which is consistent with the findings of Chaney (2008) and Eslava *et al.* (2013). Given that the period from 2006-2010 was characterised by a decline in the proportion of services imports that originated in the European Union at the same time as a significant stagnation in UK productivity, we next use the results of our analysis to examine the UK Productivity Puzzle.

3.3.3 UK Productivity Puzzle

In order to quantify the impact of the change in the EU share of UK imports in services on overall UK labour productivity for the years following the financial crisis (2007-2015), we refer to our VECM estimation results for tradable services.

We calculate (using a 'back of the envelope' approach) how much of the shortfall in UK productivity relative to a continuation of its pre-crisis trend as of 2017 Q4 can be explained by/attributed to the fall in the proportion of UK imports of services originating in the European Union starting with 2007. The EU share of UK imports in services decreased over this period by 6.13% (from 52.6% to 49.3%). The estimation results in the long run relationship equation (3.3.1) imply that the above fall in import share is associated with a fall of 6.12% in the long-run productivity level in tradable services over the same period. Given that in 2015, according to the ONS, 28% of UK GDP is made up of tradable services, the fall in productivity in the tradable services sector would result in a fall of 6.12 x 0.28 = 1.7% in overall UK productivity. The shortfall in UK productivity relative to a continuation of its pre-crisis trend, as of 2017 Q4 was 16%. Thus, our calculations show that the change in the EU share of UK imports of tradable services around the time of the Great Recession can explain about 10% of the shortfall in UK productivity relative to a continuation of its pre-crisis trend as of 2017 Q4. We therefore argue that changes in trade, in our case changes in import origin of tradable services, did impact UK labour productivity following the financial crisis, and that we offer yet another explanation which can be considered explaining the stagnation in UK productivity along the other explanations put forward in the literature, such as changes in the labour supply (Blundell *et al.* (2014), Pessoa and Van Reenen (2014), Gregg *et al.* (2014), Bell and Eiser (2015), and Patterson *et al.* (2016)), reduction in the supply of credit seen since the Great Recession and other financial factors (Oulton and Sebastia-Barriel (2013), Corry *et al.* (2011), Broadbent (2012), Franklin *et al.* (2015), Riley *et al.* (2014)), the interactions between these two (Sargent (2013) and Pessoa and Van Reenen (2014)) increase in firm survival rates among less productive firms (Barnett *et al.* (2014), Arrowsmith *et al.* (2013), Ellman (2015) and Harris and Moffat (2016)) among others.

3.4 Conclusion

There are two results that stand out from our investigation. First, in addition to the impact of the volume of imports on productivity, which had already been extensively analysed in the literature, we show that changes in the origin of imports - when caused by drivers not directly linked to competition in the importing country such as changes in tastes - can also matter for productivity, in the manner of Melitz (2003): changes in the average per-unit barrier to trade (driven in this chapter by changes in the origin of imports) lead to changes in competition, inducing adjustments in productivity. Indeed, we find that for the United Kingdom, over the period 1990-2015, in tradable services, changes in the origin of imports, driven by changes in tastes, caused changes in labour productivity.

Second, given that a large proportion of UK GDP consists of tradable services, we examine the extent to which the drop in the proportion of UK imports of services originating in the European Union seen since the 2007 financial crisis and the fall in tradable services productivity which accompanied it can explain stagnation of UK labour productivity seen since then, referred to as the UK Productivity Puzzle. Our calculations show that the changes in UK import origin from 2006 to 2014 would be associated with a 1.7% fall in UK productivity. Given that the fall in UK productivity relative to a continuation of its pre-crisis trend as of 2017 Q4 was 16%, the change in the EU share of UK imports can explain about 10% of this fall in UK productivity. Therefore, we conclude that the exogenously driven change in the share of UK imports of tradable services originating in the European Union did impact labour productivity in the UK. Thus, our results provide a complementary explanation to those already existent in the literature for the UK Productivity Puzzle (see Barnett *et al.* (2014) and Bryson and Forth (2015) for a review of this literature), as a large part of the puzzle remains unexplained.

Future research should investigate two extensions to the current analysis. First, it should focus on extending the analysis conducted in this chapter to more countries, the OECD for example, in order to explore the extent to which the relationship between the origin of imports and productivity is robust to country characteristics, such as size, geographical characteristics and trade barriers. Second, it should extend the highly aggregate analysis conducted in this chapter to greater disaggregation in order to identify which industries are the primary drivers of the causal relationship from import share to productivity in tradable services.

Chapter 4

International Trade, Non-Trading Firms and Their Impact on Labour Productivity

4.1 Introduction

In this chapter we study the role of the entry and exit of less productive non-trading domestic firms into the domestic market in driving labour productivity and its persistence, in response to shocks to macroeconomic variables. The analysis takes place in a dynamic, stochastic, general equilibrium macroeconomics model of international trade with monopolistic competition and heterogeneous firms. Recent research has thoroughly examined the effects of international trade on non-trading firms in such a framework.

For the purpose of our analysis, two important results stand out from this research. First, exports impact productivity of non-trading domestic firms thorough competition for inputs, as exporting firms demand additional labour to serve international markets, and this drives up the real wage. The increase in the real wage forces the least productive non-trading firms to exit, thus increasing average productivity. Second, imports impact labour productivity at an aggregate level thorough increased competition. Domestic firms face increased competition from importers and this forces the least productive non-trading firms to exit, thus increasing average productivity. The key papers that develop these results are: Melitz (2003), Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014), empirically supported by papers such as Amiti and Konings (2007), Yasar and Paul (2007) and Bloom *et al.* (2016). Important precursors to the analytical foundations of these results are contained in Dixit and Stiglitz (1977), Krugman (1979), Krugman (1980), Hopenhayn (1992*a*) and Hopenhayn (1992*b*).

Ghironi and Melitz (2005), Fattel Jaef and Lopez (2014) and many other important papers, make the assumption that the productivity of non-trading firms does not change as a result of the entry and exit of less productive non-trading domestic firms into the domestic market in response to macroeconomic shocks. Instead, they assume that the distribution of firm-level productivity is exogenously fixed. This assumption is appropriate when analysing the response of firms that trade internationally to macroeconomic shocks and the impact of these firms on the economy. However, this assumption may be less appealing when analysing the role of non-trading domestic firms in driving labour productivity, given that less than 1% of US firms engage in international trade (according the US Census 2016). The non-trading firms also tend to be less productive than firms that engage in international trade. A wide body of literature, such as Delgado *et al.* (2002), Andersson *et al.* (2008) and Sharma and Mishra (2015), has shown the self-selection effect, where productive firms self-select into international markets. The non-trading domestic firms are both relatively less productive and most numerous; and small macroeconomic shocks can have significant effects on their entry and exit. Unlike Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014), in our model, we allow for the entry and exit of non-trading firms into the domestic market to endogenously drive changes in the distribution of firm-level productivities.

Three recent influential papers discuss some of the issues we address in this chapter. The first is Melitz (2003). He demonstrates that the distribution of non-trading firms' productivity responds to permanent shocks to barriers to trade following changes in competition for inputs. However, his analysis is conducted in a static model and it cannot therefore examine the dynamic behaviour of the distribution of non-trading firms' productivity, nor can it examine its response to temporary shocks.

The two other related key papers are by Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014). Although the analyses in Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014) are conducted in a dynamic, stochastic, general equilibrium model, the distribution of firm-level productivity is exogenously fixed, and therefore, the impact of the entry and exit of firms into the domestic market on the productivity of domestic firms cannot be investigated. This limits their analysis of the response of productivity to macroeconomic shocks to only the extensive margin, with all changes to productivity being driven only by the entry and exit of firms. Unlike Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014) who only capture the extensive margin of production through the total number of domestic firms, we also allow for an endogenously determined productivity distribution of producing firms, capturing variations in the intensive margin of production as well. Limiting their analysis to only the extensive margins of production also limits the impact of any changes in barriers to imports, which as Bloom *et al.* (2016) show operate through both the intensive and extensive margins of production, and thus may underestimate the impact of changes in barriers to imports on productivity relative to the impact of changes in barriers to exports. According to Bloom *et al.* (2016), competition from Chinese imports alone accounts for 14% of European technological growth from 2000 to 2007 through both technological change within firms and reallocated employment between firms, as less productive firms exit the market the latter of which is ignored in Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014).

This chapter is also closely related to the recent literature examining the impact of firm entry and exit on productivity in a closed economy. The main theoretical papers, starting with Hopenhayn (1992*b*) and Hopenhayn (1992*a*), are Clementi and Palazzo (2016), Woo (2016) and Lee and Mukoyama (2018), while Moreira (2017) and Sedlacek and Stern (2017) provide important empirical examinations of the impact of firm entry and exit on productivity in a closed economy. Our chapter builds on this literature by extending the closed economy analysis of entry and exit dynamics to an open-economy framework in order to analyse the effect of international trade flows on the impact of firm entry and exit on productivity.

In this chapter we develop a model in an open economy framework that allows us to examine the role of the entry and exit of less productive non-trading domestic firms on labour productivity, through both the extensive margin of production and, by allowing endogenous changes in the firm-level productivity distribution, through the intensive margin of production as well. We conduct our analysis in a 'three-country' setup to allow for a possible future analysis of changes in trade barriers which results in trade diversion, but which we do not take up here. We use our model to analyse the extent to which the response of labour productivity to macroeconomics shocks in our model could explain the behaviour of UK productivity since the Great Recession. Despite the response of labour productivity to macroeconomics shocks being a clear question of first-order policy importance, to our knowledge, it has not been addressed so far in the class of models employed here, although such models are widely employed for policy-oriented analyses.

The rest of the chapter is organised as follows: In Section 4.2 we outline our model and discuss its features and in Section 4.3 we present the model calibration. In Section 4.4.1 we analyse the role of entry and exit of non-trading firms into the domestic market in driving labour productivity in response to shocks to macro variables. In Section 4.5 we use our model to analyse the behaviour of UK productivity since the Great Recession and examine the role the entry and exit of non-trading domestic firms in the UK market might have played in driving labour productivity. In Section 4.6 we discuss our results and offer some thought on areas for future research.

Figure 4.1: Timeline of a Period

	Period Starts	Production/Consumption	New Firm Entry	Period Ends	Exogenous Death Shock Hits	Next Period Starts
Firms	Period starts with N_{Dt} firms Firms are then hit by Exogenous Shocks	N_{Dt} firms make an average of $\tilde{d}_t$ profits over the course of the period	N_{UEt} firms pay the sunk entry cost (f_E) and attempt to enter the market of which $N_{Et} = \left(1 - G(E(z_{dt+1}))\right) N_{UEt}$ draw a productivity above $E(z_{dt+1})$ and successfully enter the market.	Existing firms draw their productivity for the following period, and remain in the market if they draw a productivity equal to or above $E(z_{dt+1})$ The period then ends with $N_{Ht} = N_{Dt} + N_{Et}$ firms	A proportion, δ, of firms are hit by the exogenous death shock, and cease to operate	Next period starts with $(1-\delta)\, N_{Ht} = N_{Dt+1}$ Firms
Households	Households start the period with holdings of bonds (B_{t-1}) and shares (x_{t-1})	Households consume C_t and are paid a total wage of $w_t L_t$, the interest on their holdings of bonds $B_{t-1} r_{t-1}$, as well as a proportion of firm profits $x_{t-1}\tilde{d}_t$ equal to their holdings of shares in the mutual fund (under financial autarky $x_{t-1} = 1$)		Households choose their holdings of Bonds B_t for which they will receive a known interest rate r_t and shares in the mutual fund x_t of existing firms (N_{Ht}) for the next period		Households start the next period with bond holdings B_t and share holdings x_t

4.2 The Model

Our basic framework builds on the model of Ghironi and Melitz (2005), the component parts of which are now familiar in the literature, therefore we develop the key equations more concisely. We develop a three-country (h, i and j) model with endogenous average firm-level productivity. Figure 4.1 presents a timeline for one period, detailing the behaviour of firms and households.

4.2.1 Households

Households are homogeneous and demand goods from both domestic and foreign producers. The representative household in country h supplies L_t^h units of labour, to only the firms in country h, at a nominal wage rate W_t^h; the real wage rate is denoted by w_t^h. The representative household maximises their expected intertemporal utility from consumption subject to their budget constraint:

$$\max_{w.r.t: C_t^h, B_t^h, x_t^h, C_{t+1}^h} E_t \sum_{s=t}^{\infty} \beta^{s-t} \left(\frac{{C_s^h}^{1-\gamma} - 1}{1-\gamma} \right),$$

$$\text{subject to: } B_t^h + \tilde{v}_t^h N_{Ht}^h x_t^h + C_t^h = (1 + r_{t-1}^h) B_{t-1}^h + (\tilde{d}_t^h + \tilde{v}_t^h) N_{Dt}^h x_{t-1}^h + w_t^h L_t^h, \quad (4.2.1)$$

where $\beta \in (0,1)$ is the subjective household discount factor, $\gamma > 0$ is the inverse of the intertemporal elasticity of substitution and C_t^h is the consumption basket, defined over a continuum of goods Ω in every period. $C_t = \left(\int_{\omega \in \Omega} c_t(\omega)^{\frac{\theta-1}{\theta}} d\omega \right)^{\frac{\theta}{\theta-1}}$, where $\theta > 1$ is the elasticity of substitution across goods, B_{t-1}^h is the consumer's holdings of bonds at the beginning of the period (chosen during the previous period), which pay a risk free rate of interest, r_{t-1}^h; x_{t-1}^h represents the consumer's holdings of shares in a mutual fund of domestic firms at the beginning of the period (chosen during the previous period); $\tilde{v}_t^h$ and $\tilde{d}_t^h$ are the average value and per-period profits of firms respectively; N_{Dt}^h is the number of firms at the start of a period and N_{Ht}^h is the number of firms at the end of the period. After the end of every period, an exogenously given proportion of firms δ dies out, thus the number of firms at the start of a period, N_{Dt}^h, will be equal to the number of firms operating in the market at the end of the previous period, N_{Ht-1}^h, adjusted to reflect the proportion of firms that die out: $N^h_{Dt} = (1-\delta)N^h_{Ht-1}$. The derivations of $\tilde{v}^h_t$, $\tilde{d}^h_t$, N^h_{Dt} and N^h_{Ht} will be presented in the next section. Additionally, we impose financial autarky: households accumulate risk free domestic bonds and shares in only the firms in their domestic economy. We also assume that there are no bubbles or 'Ponzi' schemes in the economy.

In each period, only a subset of goods, $\Omega_t \in \Omega$, will be available. Let $p^h_t(\omega)$ denote the country h currency nominal price of a good $\omega \in \Omega_t$. The consumption based price index in country h is $P^h_t = \left(\int_{\omega\in\Omega_t} p^h_t(\omega)^{1-\theta} d\omega\right)^{\frac{1}{1-\theta}}$ and the household demand, for each individual good ω, is given by $c^h_t(\omega) = \left(\frac{p^h_t(\omega)}{P^h_t}\right)^{-\theta} C^h_t$. The representative households in countries i and j solve a similar problem.

4.2.2 Firms

There is a continuum of firms in each of the three countries, h, i and j, each producing a different variety of good $\omega \in \Omega$. Firm ω employs $L_{Pt}(\omega)$ units of labour to produce output at time t. Their marginal cost in nominal terms will depend on: (i) the country specific aggregate technology level Z_t, which evolves according to an AR(1) process with persistence ρ, common to all firms within a country; (ii) the firm-level productivity z, and (iii) the nominal wage rate W_t; therefore, $MC = W_t/Z_t z$. The firm-level productivity of each firm is drawn by the firm from a distribution $G(z)$ with support on $[z_{min}, \infty)$, at the end of every period. In Ghironi and Melitz (2005) the firm level productivity, z, is drawn on market entry and fixed thereafter. Assuming that the productivity is drawn every period in our model ensures that the Melitz (2003) and Ghironi and Melitz (2005) proposition that average firm level productivity is a fixed proportion of the cutoff productivity level holds, even in the presence of fixed costs of domestic production[1]. To enter the market, and then draw a firm-level productivity for production in the following period, the firm must, as in Hopenhayn (1992*b*) and Melitz (2003), pay a

[1]Our timing assumption is the same as the timing assumption made in Cacciatore (2014), for the productivity of a specific worker-firm match

sunk entry cost, f_E, expressed in terms of effective labour units.[2] In the manner of Hopenhayn (1992*a*) and Melitz (2003), but unlike in the models in Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014), firms also have to pay a per-period fixed cost of production, f_D^h, measured in terms of effective labour units. The exporting firms will also pay a per-period costs of entering each foreign markets i and j, f_{Xi}^h and f_{Xj}^h, respectively, both measured in terms of effective labour units. In addition, exporting firms have to pay a per-unit iceberg cost such that a firm needs to export τ units of their good in order to sell one unit in the destination market. Finally, we assume that all three markets are monopolistically-competitive. The firms' problem is to maximise profits subject to their production function and the three consumer demand curves. Given that each firm produces a single variety of good, ω, and that the firms optimal behaviour is determined by their firm-level productivity level z, we move from indexing by ω to indexing by z, such that $c_t(\omega) \equiv c_t(z)$ and $p_t(\omega) \equiv p_t(z)$ for a firm with a given productivity z.

A firm with firm-level productivity z in country h solves the following constrained maximisation problem:

$$\text{Max: } d_t^h(z) = p_{Dt}^h(z)y_{Dt}^h(z) + p_{Xit}^h(z)y_{Xit}^h(z)\epsilon_i + p_{Xjt}^h(z)y_{Xjt}^h(z)\epsilon_j - W_t^h L_{Pt}^h(z)$$

$$-\frac{W_t^h f_D^h}{Z_t^h} - \frac{W_t^h f_{Xi}^h}{Z_t^h} - \frac{W_t^h f_{Xj}^h}{Z_t^h},$$

$$w.r.t: p_{Dt}^h(z), y_{Dt}^h(z), p_{Xit}^h(z), y_{Xit}^h(z), p_{Xjt}^h(z), y_{Xjt}^h(z), L_{Pt}^h(z),$$

$$\text{subject to}: y_{Dt}^h(z) + \tau_{ti}^h y_{Xit}^h(z) + \tau_{tj}^h y_{Xjt}^h(z) = zZ_t^h L_{Pt}^h(z),$$

$$y_{Dt}^h(z) = \left(\frac{p_{Dt}^h(z)}{P_t^h}\right)^{-\theta} C_t^h,$$

$$y_{Xit}^h(z) = \left(\frac{p_{Xit}^h(z)}{P_t^i}\right)^{-\theta} C_t^i,$$

$$y_{Xjt}^h(z) = \left(\frac{p_{Xjt}^h(z)}{P_t^j}\right)^{-\theta} C_t^j,$$

[2]Effective labour units are calculated as units of labour multiplied by the technology level Z_t.

where, τ^h_{it} and τ^h_{jt} are the iceberg costs of exporting from country h to countries i and j respectively at time t; for a firm with a given firm-level productivity level z in country h, $d^h_t(z)$ is its total profit, $p^h_{Dt}(z)$, $p^h_{Xit}(z)$ and $p^h_{Xjt}(z)$ are the prices of domestic goods, exports to country i and exports to country j, denominated in units of the currency of country h, i and j respectively; $y^h_{Dt}(z)$, $y^h_{Xit}(z)$ and $y^h_{Xjt}(z)$ are the total units of goods sold by the firm in the domestic market and countries i and j respectively, we assume that supply matches demand: $y_t(z) = c_t(z)$; $L^h_{Pt}(z)$ is the amount of labour used in production; C^h_t, C^i_t and C^j_t are aggregate consumption in countries h, i and j respectively; P^h_t, P^i_t and P^j_t are the consumption-based price indices of countries h, i and j and, ϵ_i and ϵ_j are the nominal exchange rates (units of h currency per unit of i and j currency) between country h and countries i and j respectively.

Solving this problem, the firm sets their output price as a mark-up over the marginal cost, where the mark-up is given by $\theta/(\theta-1)$. Given this, the real prices of the firm's goods in each market are as follows: the real price of domestic goods in country h is $\rho^h_{Dt}(z) = \frac{p^h_{Dt}(z)}{P^h_t} = \frac{\theta}{\theta-1}\frac{w^h_t}{Z^h_t z}$, the real price of goods exported to country i from country h is $\rho^h_{Xit}(z) = \frac{p^h_{Xit}(z)}{P^i_t} = \frac{\tau^h_{it}}{Q^i_t}\rho^h_{Dt}(z)$, and the real price of goods exported to country j from country h is $\rho^h_{Xjt}(z) = \frac{p^h_{Xjt}(z)}{P^j_t} = \frac{\tau^h_{jt}}{Q^j_t}\rho^h_{Dt}(z)$, where Q^i_t is the real exchange rate between country h and country i, equal to $\epsilon_i\frac{P^i_t}{P^h_t}$, Q^j_t is the real exchange rate between country h and country j, equal to $\epsilon_j\frac{P^j_t}{P^h_t}$ and $w^h_t = W^h_t/P^h_t$ is the real wage. Equivalent price equations hold for countries i and j.

Total firm profits are given by the sum of profit from domestic sales, d^h_{Dt}, and potential profit from exporting, d^h_{Xit} and d^h_{Xjt}, to countries i and j respectively. Given the fixed costs of domestic production and exporting, there will be some firms that do not draw high enough firm-level productivity to make a profit (or break even) in the domestic market, who then exit the market entirely, and some firms that do not export to one or the other of the two foreign markets. Therefore, there are cutoff productivity levels below which a firm will not produce for either the domestic market, $z^h_{Dt} = \inf\{z : d^h_{Dt} \geq 0\}$ or for each of the foreign markets,

$z^h_{Xit} = \inf\{z : d^h_{Xit} \geq 0\}$ and $z^h_{Xjt} = \inf\{z : d^h_{Xjt} \geq 0\}$ for exports to countries i and j respectively.

We assume that the lower bound of the productivity distribution z_{min} is low enough compared to the domestic cutoff level z^h_{Dt}, such that this is above z_{min}. We further assume that the domestic cutoff level, z^h_{Dt}, is low enough relative to the export cutoff levels z^h_{Xit} and z^h_{Xjt} such that both z^h_{Xit} and z^h_{Xjt} are above z^h_{Dt}. These assumptions ensure that: 1) there will be an endogenously determined subset of firms that pay the sunk entry cost f_E, but do not produce for the domestic market, and 2) there will be an endogenously determined non-traded sector - the firms with productivities between z^h_{Dt} and the lower of z^h_{Xit} and z^h_{Xjt}. The subset of firms that pay the sunk entry cost, but do not draw a productivity at the end of the period above the expected cutoff level for domestic production immediately exit the market. Therefore, if they want to enter the market again and try to then draw a productivity above the cutoff level they must pay the sunk entry cost again. Firm profits are therefore:

$$d^h_t(z) = d^h_{Dt}(z) + d^h_{Xit}(z) + d^h_{Xjt}(z),$$

$$d^h_{Dt}(z) = \begin{cases} \frac{1}{\theta}(\rho^h_{Dt}(z))^{1-\theta}C_t - \frac{w^h_t f^h_D}{Z^h_t} & \text{if } z \geq z^h_{Dt}, \\ 0 & \text{otherwise,} \end{cases} \tag{4.2.2}$$

$$d^h_{Xit}(z) = \begin{cases} \frac{Q^i_t}{\theta}(\rho^h_{Xit}(z))^{1-\theta}C^i_t - \frac{w^h_t f^h_{Xi}}{Z^h_t} & \text{if } z \geq z^h_{Xit}, \\ 0 & \text{otherwise,} \end{cases} \tag{4.2.3}$$

$$d^h_{Xjt}(z) = \begin{cases} \frac{Q^j_t}{\theta}(\rho^h_{Xjt}(z))^{1-\theta}C^j_t - \frac{w^h_t f^h_{Xj}}{Z^h_t} & \text{if } z \geq z^h_{Xjt}, \\ 0 & \text{otherwise.} \end{cases} \tag{4.2.4}$$

In Ghironi and Melitz (2005) the first equation, giving profits from domestic production, will simply be as follows, without the fixed cost of domestic production, $d^h_{Dt}(z) = \frac{1}{\theta}(\rho^h_{Dt}(z))^{1-\theta}C_t$, as all firms will produce for the domestic market. Equivalent firm profit equations hold for countries i and j.

Firm Averages

In every period there is a number of firms, N^h_{Dt}, that produce for the domestic market, given the cutoff level of domestic production, z^h_{Dt}. A number of these firms, given by N^h_{Xit} and N^h_{Xjt}, export to countries i and j respectively. In a similar manner to Melitz (2003), we define 'average' productivity for all domestic firms, $\tilde{z}^h_D$, and for firms that export to countries i and j, $\tilde{z}^h_{Xi}$ and $\tilde{z}^h_{Xj}$, as:

$$\tilde{z}^h_{Dt} = \left[\frac{1}{1 - G(z^h_{Dt})} \int_{z^h_{Dt}}^{\infty} z^{\theta-1} dG(z) \right]^{\frac{1}{\theta-1}},$$

$$\tilde{z}^h_{Xit} = \left[\frac{1}{1 - G(z^h_{Xit})} \int_{z^h_{Xit}}^{\infty} z^{\theta-1} dG(z) \right]^{\frac{1}{\theta-1}},$$

$$\tilde{z}^h_{Xjt} = \left[\frac{1}{1 - G(z^h_{Xjt})} \int_{z^h_{Xjt}}^{\infty} z^{\theta-1} dG(z) \right]^{\frac{1}{\theta-1}}.$$

Melitz (2003) shows that these productivity averages contain all the information on the productivity distributions relevant for macroeconomic variables. Thus, our model is isomorphic to a model where N^h_{Dt} firms with productivity $\tilde{z}^h_{Dt}$ produce for the domestic market, and N^h_{Xit} and N^h_{Xjt} firms with productivities $\tilde{z}^h_{Xit}$ and $\tilde{z}^h_{Xjt}$ produce for each of the two export markets. The average price in the domestic market, will be equal to the price of the firm with average productivity, $\tilde{p}^h_{Dt} = p^h_{Dt}(\tilde{z}^h_{Dt})$ and the average price in each of the exporting markets will be equal to the price of the exporting firms with average productivities $\tilde{p}^h_{Xit} = p^h_{Xit}(\tilde{z}^h_{Xit})$ and $\tilde{p}^h_{Xjt} = p^h_{Xjt}(\tilde{z}^h_{Xjt})$. The nominal price index in country h reflects the nominal price of both domestic firms and imports from foreign firms. The nominal price index can therefore be written as:

$$P^h_t = [N^h_{Dt}(\tilde{p}^h_{Dt})^{1-\theta} + N^i_{Xht}(\tilde{p}^i_{Xht})^{1-\theta} + N^j_{Xht}(\tilde{p}^j_{Xht})^{1-\theta}]^{\frac{1}{1-\theta}}.$$

Dividing both sides by ${P^h_t}^{1-\theta}$ we obtain the following real price index:

$$N^h_{Dt}(\tilde{\rho}^h_{Dt})^{1-\theta} + N^i_{Xht}(\tilde{\rho}^i_{Xht})^{1-\theta} + N^j_{Xht}(\tilde{\rho}^j_{Xht})^{1-\theta} = 1. \quad (4.2.5)$$

Equivalent price index equations hold for countries i and j.

Average total profits are given by the sum of average profits from domestic sales and average profits from exporting, adjusted to the proportion of firms that export to a each market:

$$\tilde{d}_t^h = \tilde{d}_{Dt}^h + \frac{1 - G(z_{Xit}^h)}{1 - G(z_{Dt}^h)} \tilde{d}_{Xit}^h + \frac{1 - G(z_{Xjt}^h)}{1 - G(z_{Dt}^h)} \tilde{d}_{Xjt}^h.$$

This equation can then be written explicitly with the ratios of exporting firms to total domestic firms:

$$\tilde{d}_t^h = \tilde{d}_{Dt}^h + \frac{N_{Xit}^h}{N_{Dt}^h} \tilde{d}_{Xit}^h + \frac{N_{Xjt}^h}{N_{Dt}^h} \tilde{d}_{Xjt}^h. \tag{4.2.6}$$

Equivalent average total profit equations hold for each of the two foreign countries, i and j.

Firm Value

All producing firms, other than the firm with productivity equal to the cutoff level ($z = z_{Dt}^h$), make positive profits. Thus, the average profit level in country h will be positive ($\tilde{d}_t^h > 0$), and the average firm will have a positive value, derived from expected future profits. After the end of a period, an exogenously determined proportion δ of firms in each country will cease to operate. Given that these firms cease to operate after new entrants have entered the market, a proportion δ of the successful new entrants will never operate. Since households own the firms, we can solve the households' problem to calculate the average value of firms in the economy, $\tilde{v}_t^h$. Given that the firms are owned entirely by domestic households the value of a firm on entry will be given by the limit of the household share Euler equation: If we assume that there are no bubbles in the economy then $\lim_{j\to\infty} \tilde{\beta}_{t+j} \tilde{v}_{t+j} = 0$, where $\tilde{\beta}_{t+j} = [\beta(1-\delta)]^j E_t \left(\frac{C_{t+j}^h}{C_t^h}\right)^{-\gamma}$, then the value of a firm will be equal to the discounted present value of its expected profit stream:

$$\tilde{v}_t^h = E_t \sum_{s=1}^{\infty} [\beta(1-\delta)]^s \left(\frac{C_{t+s}^h}{C_t^h}\right)^{-\gamma} \tilde{d}_{t+s}^h.$$

Thus, as long as $\tilde{d}_t^h$ is positive, the average firm value in country h will also be positive ($\tilde{v}_t^h > 0$).

Firm Entry and Exit

In each period, N_{UEt}^h new firms will pay the sunk entry cost to commence production, and then at the end of the period, draw a firm-level productivity, z, for production in the following period. Upon drawing their productivity, some firms will have a productivity less than the expected cutoff level for domestic production in the following period, $E_t(z_{Dt+1}^h)$, thus a proportion of firms, $G((z_{Dt+1}^h))$, that pay the entry cost will not produce, as they draw a productivity below the expected cutoff level and will instead exit the market immediately. Firms will choose to enter the market until the average firm value, which, unlike in Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014), is adjusted by the probability of successfully entering the market, is equal to the initial entry cost, f_E^h, expressed in effective labour units, which leads to the free entry condition:

$$\tilde{v}_t^h(1 - G(E_t(z_{Dt+1}^h))) = \frac{w_t^h f_E^h}{Z_t^h}, \tag{4.2.7}$$

which, rearranged, is:

$$\tilde{v}_t^h = \frac{1}{1 - G(E_t(z_{Dt+1}^h))} \frac{w_t^h f_E^h}{Z_t^h}.$$

The number of firms operating at the end of the period, N_{Ht}^h, will be equal to the number of firms operating at the start of the period, N_{Dt}^h, plus the number of successful new entrants N_{Et}^h. The number of successful new entrants will be equal to the number of firms that pay the entry cost, N_{UEt}^h, adjusted by the probability of entering the market: $N_{Et}^h = (1 - G(E_t(z_{Dt+1}^h)))N_{UEt}^h$. The number of firms at the end of the period will therefore be given by: $N_{Ht}^h = N_{Dt}^h + N_{Et}^h = N_{Dt}^h + (1 - G(E_t(z_{Dt+1}^h)))N_{UEt}^h$. Given the timing of firm entry and exit we have assumed, the number of firms operating during a period will be given by:

$$N_{Dt}^h = (1-\delta)N_{Ht-1}^h = (1-\delta)(N_{Dt-1}^h + N_{Et-1}^h). \tag{4.2.8}$$

Note that, because the total number of firms can only change endogenously at the end of the period, the average productivity of domestic production during a period, $\tilde{z}_{Dt}^h$, will be predetermined during a period, and will only change in between periods, as a result of the entry and exit of less productive non-trading firms from the domestic market.

4.2.3 Parametrising Productivity

In order to solve the model we assume that the firm-level productivities, z, follow a Pareto distribution with lower bound z_{min} and shape parameter k. We assume that $k > \theta - 1$ to ensure that the average of firm size is finite[3]. Thus, we have $G(z) = 1 - (z_{min}/z)^k$.

Average firm-level productivities are then: $\tilde{z}_D^h = \nu z_{Dt}^h$, $\tilde{z}_{Xit}^h = \nu z_{Xit}^h$, $\tilde{z}_{Xjt}^h = \nu z_{Xjt}^h$, where $\nu = [k/(k-(\theta-1))]^{\frac{1}{\theta-1}}$.

The proportion of country h firms that export to each market is given by:

$$\frac{N_{Xit}^h}{N_{Dt}^h} = \frac{1-G(z_{Xit}^h)}{1-G(z_{Dt}^h)},$$

$$\frac{N_{Xjt}^h}{N_{Dt}^h} = \frac{1-G(z_{Xjt}^h)}{1-G(z_{Dt}^h)}.$$

Using *G(z)* and average firm-level productivities, these can then be rewritten as:

$$\frac{N_{Xit}^h}{N_{Dt}^h} = \frac{\left(\frac{z_{min}^h}{z_{Xit}^h}\right)^k}{\left(\frac{z_{min}^h}{z_{Dt}^h}\right)^k} = (\tilde{z}_{Dt}^h)^k(\tilde{z}_{Xit}^h)^{-k}, \tag{4.2.9}$$

[3] According to Axtell (2001), $k/(\theta-1)$ is around 1.06 in the US.

$$\frac{N^h_{Xjt}}{N^h_{Dt}} = \frac{\left(\frac{z^h_{min}}{z^h_{Xjt}}\right)^k}{\left(\frac{z^h_{min}}{z^h_{Djt}}\right)^k} = (\tilde{z}^h_{Dt})^k(\tilde{z}^h_{Xjt})^{-k}. \tag{4.2.10}$$

Equivalent equations for the proportion of firms that export hold for countries i and j.

Given the parametrisation of $G(z^h_{Dt})$, we rewrite the free entry condition (4.2.7) :

$$\tilde{v}^h_t = \frac{1}{1 - G(E_t(z^h_{Dt+1}))}\frac{w^h_t f^h_E}{Z^h_t} = \left(\frac{E_t(z^h_{Dt+1})}{z^h_{min}}\right)^k \frac{w^h_t f^h_E}{Z^h_t}. \tag{4.2.11}$$

Equivalent free entry conditions hold for countries i and j.

The country h zero domestic profit cutoff condition $d^h_{Dt}(z^h_{Dt}) = 0$, zero export profit cutoff conditions $d^h_{Xit}(z^h_{Xit}) = 0$ and $d^h_{Xjt}(z^h_{Xjt}) = 0$, and equations (4.2.2), (4.2.3) and (4.2.4) for firm profits, imply that country h average domestic profits and average export profits to each market will satisfy:

$$\tilde{d}^h_{Dt} = (\theta - 1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w^h_t f^h_D}{Z^h_t}, \tag{4.2.12}$$

$$\tilde{d}^h_{Xit} = (\theta - 1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w^h_t f^h_{Xi}}{Z^h_t}, \tag{4.2.13}$$

$$\tilde{d}^h_{Xjt} = (\theta - 1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w^h_t f^h_{Xj}}{Z^h_t}. \tag{4.2.14}$$

In a similar manner to the domestic profits equation, (4.2.2), the domestic zero profit equation above differs from Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014). In these papers, given that there is no fixed cost of domestic production, all firms produce for the domestic market, and therefore no zero domestic profit cutoff condition exists. Equivalent zero profit conditions will hold for countries i and j.

4.2.4 Market Clearing

The wage rate in each country will adjust such that the exogenously set labour supply is equal to the sum of labour used in production, labour used as a sunk cost of entry, labour used as fixed costs of domestic production, and labour used as fixed costs of exporting to each foreign market. The resultant labour market clearing condition is:

$$L_t^h = L_{Pt}^h + \left(\frac{E_t(z_{Dt+1}^h)}{z_{min}^h}\right)^k \frac{N_{Et}^h f_{Et}^h}{Z_t^h} + \frac{N_{Dt}^h f_{Dt}^h}{Z_t^h} + \frac{N_{Xit}^h f_{Xit}^h}{Z_t^h} + \frac{N_{Xjt}^h f_{Xjt}^h}{Z_t^h}, \quad (4.2.15)$$

where $L_{Pt}^h = (Y_{Dt}^h/z_{Dt}^h + Y_{Xit}^h/z_{Xit}^h + Y_{Xjt}^h/z_{Xjt}^h)/Z_t^h$ is the labour used in production, equal to the sum of labour used in domestic production, $Y_{Dt}^h/Z_t^h z_{Dt}^h$, and the labour used in producing for both export markets, $Y_{Xit}^h/Z_t^h z_{Xit}^h$ and $Y_{Xjt}^h/Z_t^h z_{Xjt}^h$ for exports to i and j respectively, where Y_{Dt}^h, Y_{Xit}^h and Y_{Xjt}^h are, respectively the total number of units of output produced for the domestic market, and for exporting to countries i and j.

Given that we have assumed no government borrowing, no physical capital and financial autarky, aggregate bond holdings must equal zero at the end of the period, and the aggregate number of shares per company must equal unity. The assumption of financial autarky (value of exports=value of imports) for all countries, also yields the balanced trade equation:

$$Q_t^i N_{Xit}^h (\tilde{\rho}_{Xit}^h)^{1-\theta} C_t^i + Q_t^j N_{Xjt}^h (\tilde{\rho}_{Xjt}^h)^{1-\theta} C_t^j = N_{Xht}^i (\tilde{\rho}_{Xht}^i)^{1-\theta} C_t^h + N_{Xht}^j (\tilde{\rho}_{Xht}^j)^{1-\theta} C_t^h. \quad (4.2.16)$$

Equivalent labour market clearing and balanced trade equations will hold for countries i and j.

4.2.5 Model Summary

Table B1 in the Appendix summarizes the main equilibrium conditions of the model. The equations in this table constitute a system of 56 equations in 56 endogenous variables: w_t^h, w_t^i, w_t^j, $\tilde{\rho}_{Dt}^h$, $\tilde{\rho}_{Dt}^i$, $\tilde{\rho}_{Dt}^j$, $\tilde{\rho}_{Xit}^h$, $\tilde{\rho}_{Xjt}^h$, $\tilde{\rho}_{Xht}^i$, $\tilde{\rho}_{Xjt}^i$, $\tilde{\rho}_{Xht}^j$, $\tilde{\rho}_{Xit}^j$, $\tilde{d}_t^h$, $\tilde{d}_t^i$, $\tilde{d}_t^j$, $\tilde{d}_{Dt}^h$, $\tilde{d}_{Dt}^i$, $\tilde{d}_{Dt}^j$, $\tilde{d}_{Xit}^h$, $\tilde{d}_{Xjt}^h$, $\tilde{d}_{Xht}^i$, $\tilde{d}_{Xjt}^i$, $\tilde{d}_{Xht}^j$, $\tilde{d}_{Xit}^j$, N_{Dt}^h, N_{Dt}^i, N_{Dt}^j, N_{Et}^h, N_{Et}^i, N_{Et}^j, N_{Xit}^h, N_{Xjt}^h, N_{Xht}^i, N_{Xjt}^i, N_{Xht}^j, N_{Xit}^j, $\tilde{z}_{Dt}^h$, $\tilde{z}_{Dt}^i$, $\tilde{z}_{Dt}^j$, $\tilde{z}_{Xit}^h$, $\tilde{z}_{Xjt}^h$, $\tilde{z}_{Xht}^i$, $\tilde{z}_{Xjt}^i$, $\tilde{z}_{Xht}^j$, $\tilde{z}_{Xit}^j$, $\tilde{v}_t^h$, $\tilde{v}_t^i$, $\tilde{v}_t^j$, r_t^h, r_t^i, r_t^j, C_t^h, C_t^i, C_t^j, Q_t^i and Q_t^j. Of these endogenous variables, 9 are predetermined as of time t: the total numbers of firms in each country N^h_{Dt}, N^i_{Dt} and N^j_{Dt}, the average firm level productivities, $\tilde{z}^h_{Dt}$, $\tilde{z}^i_{Dt}$ and $\tilde{z}^j_{Dt}$ and the risk-free interest rates, r^h_t, r^i_t and r^j_t. Additionally, the model features 21 exogenous variables: the aggregate productivities Z^h_t, Z^i_t and Z^j_t, and the policy variables f^h_{Et}, f^i_{Et}, f^j_{Et}, f^h_{Dt}, f^i_{Dt}, f^j_{Dt}, f^h_{Xit}, f^h_{Xjt}, f^i_{Xht}, f^i_{Xjt}, f^j_{Xht}, f^j_{Xit}, τ^h_{it}, τ^h_{jt}, τ^i_{ht}, τ^i_{jt}, τ^j_{ht} and τ^j_{it}. Changes in f^h_{Xit}, f^h_{Xjt}, f^i_{Xht}, f^i_{Xjt}, f^j_{Xht}, f^j_{Xit}, τ^h_{it}, τ^h_{jt}, τ^i_{ht}, τ^i_{jt}, τ^j_{ht} and τ^j_{it} reflect changes in trade policy. For country h, the trade policy instruments will be f^h_{Xit}, f^h_{Xjt}, τ^h_{it} and τ^h_{jt}, for country i, the trade policy instruments will be f^i_{Xht}, f^i_{Xjt}, τ^i_{ht} and τ^i_{jt}, and for country j, the trade policy instruments will be f^j_{Xht}, f^j_{Xit}, τ^j_{ht} and τ^j_{it}.

4.3 Calibration

The papers we address here, such as Ghironi and Melitz (2005), assume complete symmetry between the countries in their models, including in terms of country size and barriers to trade. We take a different approach. We allow for asymmetries in country size and barriers to trade, and we calibrate our model accordingly. We interpret periods as three months, which determines the discount factor $\beta = 0.99$, and the risk aversion parameter $\gamma = 2$, standard values in quarterly business cycle models. The firm exit rate, δ, is set to 0.0235, such as to match the 9.4% UK annual firm death rate.[4] Following Bernard *et al.* (2003), θ is set to 3.8[5] and k is set to 3.4, satisfying the condition that $k > \theta - 1$.

The three countries in the model are set as the UK (h), the EU (i) and the Rest of the World (RoW) (j), where RoW is defined as all countries in the world that are not members of the European Union. The per unit iceberg costs τ were calculated using data from the *World Bank Trade Costs* database, and the *ONS Pink Book*. The *World Bank Trade Costs* database provides the tariff equivalent

[4]Firm death rate is obtained from the *ONS Business Demography Statistics* (2016).

[5]We note that, although the value of θ may appear low (standard macro literature sets $\theta = 6$ to deliver a 20% mark-up over marginal cost), the mark-up in this chapter represents mark-up over average cost, including the entry cost. We have conducted sensitivity analyses on the value of θ, and all values from 1.9 to 4.5 give similar responses to model simulations.

rate, x, for trade between pairs of countries, which allows the calculation of the average tariff equivalent rate for 2005-2015 for each country pair. These tariff equivalent rates were then mapped into an iceberg cost, IC, for each country pair according to: $IC = x/(1 + x)$.

The iceberg costs were calculated individually for UK imports from the EU, UK imports from the RoW, UK exports to the EU and UK exports to the RoW as a weighted average on the basis of total exports/imports from each country. For example, the iceberg cost for UK exports to the EU was calculated as the sum of: the iceberg cost for UK trade with each European country multiplied by the proportion of UK exports going to each European country. Given that the UK and the EU are part of a customs union and share similar geographic characteristics, we assume that the iceberg costs of exporting and importing from the EU to the RoW are the same as the iceberg costs of exporting and importing from the UK to the RoW. The iceberg costs are therefore as follows: $\tau_i^h = 1.316, \tau_j^h = 1.450, \tau_h^i = 1.326, \tau_j^i = 1.450, \tau_h^j = 1.459$ and $\tau_i^j = 1.459$.[6]

The fixed costs of exporting from the UK to the EU and UK to the RoW are calibrated such that the proportion of UK firms that export to the EU, and to the RoW match the proportions reported by the ONS *Annual Business Survey of Importers and Exporters* (approximately 7% and 8%, respectively). The remaining fixed exporting costs are then set in the same proportions as the iceberg costs. The fixed costs of domestic production in the EU and RoW are calibrated such that the number of firms in the EU and RoW are 9.93 and 24.2 times the number of firms in the UK, to match data from *Eurostat* and the *World Bank*. As in de Soyres (2016) we then normalize the fixed cost of domestic production in the UK so that no domestic entry threshold lies below the lower bound of the productivity distribution.

[6]Although the iceberg costs appear high, particularly for UK-EU trade (given the absence of formal trade barriers) their values reflect not only the cost of formal barriers to trade, but also other costs of exporting, such as language barriers and transport costs.

We normalise f_E, z_{min} and Z to 1 for all three countries[7] as well as normalising the labour force in the UK to 1. Finally, the labour forces in the EU and RoW were set such that, in the calibrated model, UK GDP is equal to 1/6.58 of EU GDP and 1/24.2 of RoW GDP, in line with 2017 *World Bank* data. Table B2 in the appendix sets out the full parameter values used for the calibration.

4.4 Transmission of Macroeconomic Shocks

In this section we examine how the entry and exit of less productive non-trading firms effects the transmission of macroeconomic shocks. First, we analyse the impact of different transitory macroeconomic shocks on productivity and its persistence. Second, we examine the relative impact of changes in barriers to imports and barriers to exports. Third, we analyse the impact of permanent macroeconomic shocks on various macroeconomic variables. The first analysis seeks to provide an explanation for the wide variation in empirically calculated figures for the persistence of labour productivity which range from 0.85 in Pancrazi and Vukotic (2011) to 0.906 in Backus *et al.* (1992) and 0.994 in Baxter (1995), by analysing how the persistence of labour productivity varies in our framework depending on the source of the macroeconomic shock. The second analysis seeks to examine whether changes in barriers to imports or exports have a greater impact on productivity. Intuitively, given that barrier to import changes directly affect all firms in the economy, while barrier to export changes directly affect only trading firms, barrier to import changes would have a larger impact on productivity. However, existing models such as Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014) are not able to replicate this result, and barrier to export changes have a much larger impact on productivity. The third analysis seeks to determine how the entry and exit of less productive non-trading firms affects the response of the

[7] Changing the entry cost, f_E, and the fixed cost of domestic production, f_D, while maintaining the same ratios f_X/f_E and f_D/f_E does not have any effect on the firm-level productivity variables, z_D and z_X, as they are determined by the free entry condition and the zero profit conditions. Changing f_E, f_D and f_X by the same proportion will not alter the calibrated values for firm-level productivity.

economy to permanent macroeconomic shocks, by comparing the response in our framework to the responses in the baseline Ghironi and Melitz (2005) framework, where the productivity distribution is exogenously fixed.

For the purpose of our analysis, to match output per worker productivity data as closely as possible, we adopt the definition for aggregate productivity specified in Kehrig (2015). Productivity is defined as total output divided by the sum of labour used in production, labour used to pay the fixed costs of domestic production and labour used to pay the fixed costs of exporting to each foreign market:

$$Z_O^h = \frac{Y_t^h}{L_{Pt}^h + F_t^h},$$

where Y_t^h is total output, L_{Pt}^h is labour used in production, as defined earlier and F_t^h is the labour used to pay the fixed costs, equal to the sum of the labour used to pay the fixed costs of domestic production $\frac{N_{Dt}^h f_{Dt}^h}{Z_t^h}$ and the fixed costs of exporting to each foreign market $\frac{N_{Xit}^h f_{Xit}^h}{Z_t^h}$ and $\frac{N_{Xjt}^h f_{Xjt}^h}{Z_t^h}$ for exports to i and j respectively. Total output will be made up of output for the domestic market, Y_{Dt}^h, and output for each foreign market, Y_{Xit}^h and Y_{Xjt}^h for exports to the EU and RoW respectively. Note that, because of the variable iceberg costs of exporting, the output for exporting will be equal to the number of units sold in each foreign market, multiplied by the iceberg cost of exporting to that market. All future references to labour productivity should be taken to refer to productivity as measured above.

4.4.1 Endogenous Productivity Persistence

In this sub-section we examine the impact of transitory shocks to aggregate technology, sunk entry costs and the fixed costs of domestic production on the persistence of labour productivity, and quantify the extent of this impact for the first two shocks, in order to provide a possible explanation for the wide variation in empirically calculated figures for the persistence of labour productivity, which range from 0.85 in Pancrazi and Vukotic (2011) to 0.906 in Backus *et al.* (1992) and 0.994 in Baxter (1995). The introduction of the entry and exit of less-productive non-trading domestic firms into our model allows the persistence of labour productivity to vary endogenously in response to different macroeconomic shocks, unlike in existing models, such as the models in Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014).

Figure 4.2 shows the response of labour productivity in country h to three different macroeconomic shocks: a one period, 1 percentage point positive shock to aggregate technology, Z^h, shown by the dashed line; a one period, 3.56 percentage point negative shock to the sunk costs of entry, f_E^h, shown by the dotted line; and a one period, 2.88 percentage point positive shock to the fixed costs of domestic production, f_D^h, shown by the dot-dash line. The solid line shows the time path of the shocks themselves and the length of time (in quarters) after the shock is on the horizontal axis. Figure 4.3 shows the response of labour productivity in the closed economy version of the model, where it is assumed that countries do not trade internationally to the three types of macroeconomic shocks as in Figure 4.2: a one period, 1 percentage point positive shock to aggregate technology, Z^h, shown by the dashed line; a one period, 3.65 percentage point negative shock to the sunk costs of entry f_E^h, shown by the dotted line; and a one period, 1.53 percentage point positive shock to the fixed costs of domestic production, f_D^h, shown by the dot-dash line. Finally, the solid line shows the time path of the shocks themselves and the length of time (in quarters) after the shock is on the horizontal axis. In both the open and closed economy cases, the shock size is set such that the initial response of labour productivity is 1% above its steady-state level.

We assume that these shocks hit at the beginning of the period, before production starts, and follow an AR(1) processes:

$$\hat{Z}_t^h = \rho * \hat{Z}_{t-1}^h + \epsilon_t,$$

$$\hat{f}_{Et}^h = \rho * \hat{f}_{Et-1}^h + \epsilon_t,$$

$$\hat{f}_{Dt}^h = \rho * \hat{f}_{Dt-1}^h + \epsilon_t,$$

Figure 4.2: Open Economy Response of Labour Productivity to Macroeconomic Shocks

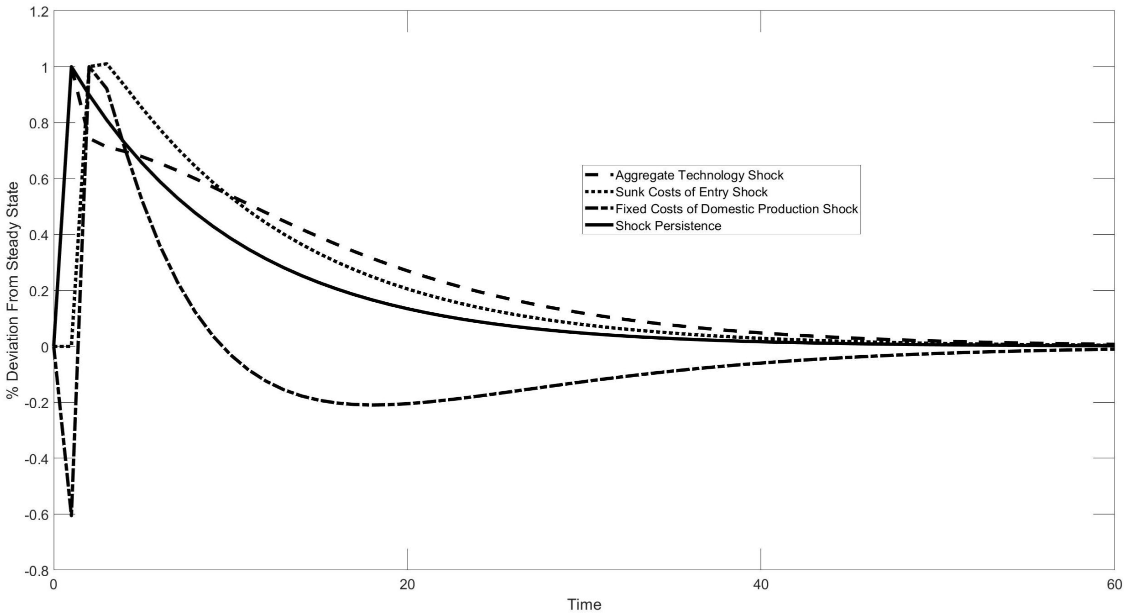
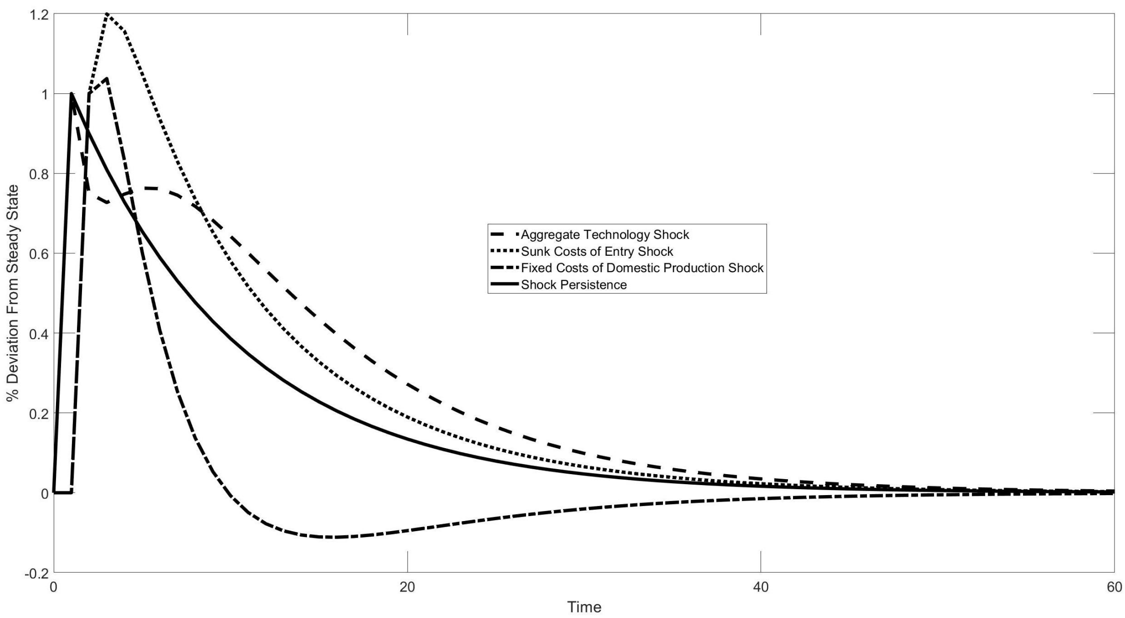


Figure 4.3: Closed Economy Response of Labour Productivity to Macroeconomic Shocks



where $\hat{Z}_t^h$, $\hat{f}_{Et}^h$ and $\hat{f}_{Dt}^h$ are the deviations of aggregate technology, sunk costs of entry and fixed costs of domestic production respectively, from their steady-state levels, in period t, ρ is the exogenously set persistence of shocks and ϵ_t is the magnitude of the shock in period t. We assume that the persistence of the shocks, exogenously given, is equal to $\rho = 0.90$, as in Ghironi and Melitz (2005).[8]

If the distributions of firm productivities were fixed exogenously, then in both the open and closed economies, the persistence of labour productivity would have been solely determined by the exogenously given persistence parameter for the macroeconomic shocks, ρ, as is the case in standard RBC models. However, when the distribution of firm productivities is endogenously determined through endogenous changes in the cut-off productivity levels, an endogenous degree of persistence is now present in the response of labour productivity to each of these shocks. The extent to which this is the case, depends on the source of the macroeconomic shock, and whether the shock is occurring in an open or closed economy setting:

1. An aggregate technology shock, Z^h, in both the open and closed economy settings, induces labour productivity, Z^h_O, to return to its steady-state level at a much slower rate than aggregate technology, due to the behaviour of the average firm-level productivity, z^h_D. Firm-level productivity remains above its steady-state level for a significantly longer period of time than aggregate technology. The half life of productivity in response to the aggregate technology shock is 14 periods in the open economy and 16 periods in the closed economy, compared to a half life of 8 periods for the shock itself. Over these time periods, this is equivalent to a persistence of 0.952 for productivity in the open economy and 0.953 in the closed economy, compared to a shock persistence of 0.9. Comparing these results to Fattel Jaef and Lopez (2014), where the distribution of firm-level productivity is exogenously fixed, we see that allowing for an endogenous firm-level productivity response, through the entry and exit of less productive non-trading firms, introduces further endogenous persistence to the response of productivity. In their paper, the half life of productivity (in the open economy framework) is approximately

[8] We conduct robustness checks on the value of ρ, examining the responses of labour productivity for a range of values from $\rho = 0.85$, as in Pancrazi and Vukotic (2011) to $\rho = 0.994$, as in Baxter (1995). For this range of values, the responses were similar in all cases. Results are available on request.

12 periods, with an approximate total TFP persistence of 0.95, lower than in both the open and closed economy versions of our model.

2. A shock to the sunk costs of entry, f_E^h, in both the open and closed economy settings, induces labour productivity, Z_O^h, to return to its steady-state level at a much slower rate than the sunk cost of entry, but quicker than in the case of a shock to aggregate technology, due to the behaviour of the average firm-level productivity, z_D^h. Firm-level productivity remains above its steady-state level for a significantly longer time than aggregate technology. The half life of productivity in response to the aggregate technology shock is 13 periods in the open economy and 14 periods in the closed economy, compared to a half life of 8 periods for the shock itself. Over these time periods, this is equivalent to a persistence of 0.938 for productivity in the open economy and 0.945 in the closed economy, compared to a shock persistence of 0.9.

3. In the case of a shock to the fixed costs of domestic production, f_D^h, in both the open and closed economies, the persistence of labour productivity is significantly lower than the persistence of the shock itself, driven by the rapid entry of less productive firms, when initial lower profits drive firms off the market resulting in less initial competition. In this case, labour productivity falls below its initial steady-state level, before slowly returning to it, as the shock dissipates.

The different persistence of labour productivity between the open and closed economies and across the various macroeconomic shocks studied here is driven by the responses of firms and consumers which differ in each case. Thus, in Figures 4.4, 4.5 and 4.6 we show the dynamic response of consumption, C^h, average productivity for domestic production, $\tilde{z}_D^h$, labour productivity, Z_O^h, the real wage, w^h, the number of firms, N_D^h, and the number of new entrants, N_E^h, to the one period transitory shocks, outlined above, to aggregate technology, the sunk costs of entry and the fixed costs of domestic production, respectively. The solid lines plot the response in the open economy, while the dotted lines plot the response in the closed economy.

Figure 4.4: Response to Transitory Aggregate Technology (Z^h) Shock

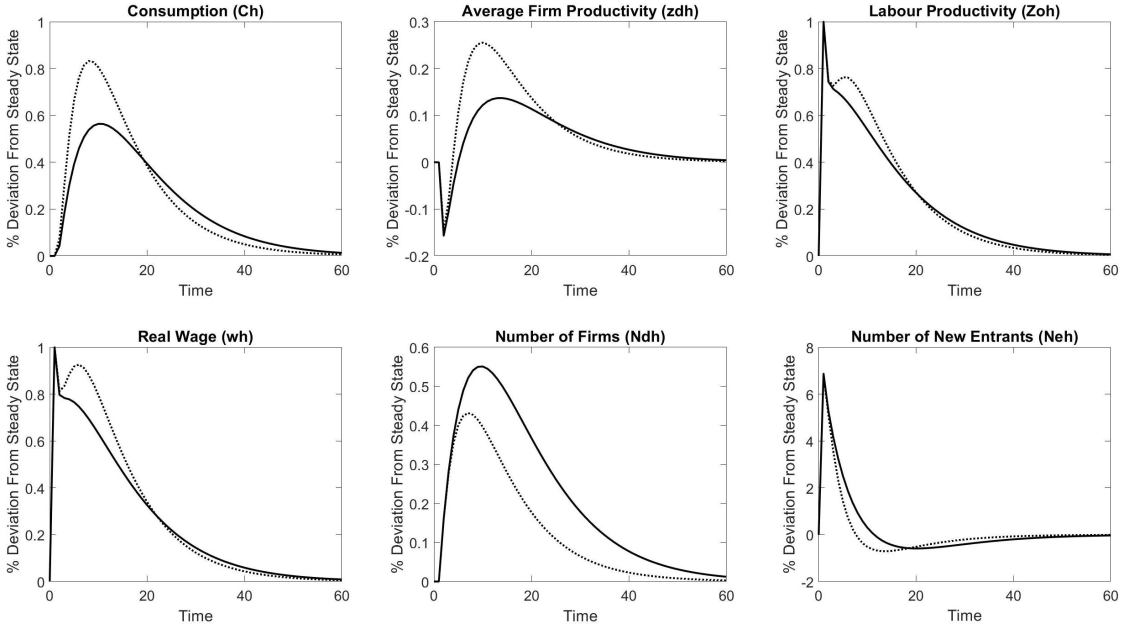


Figure 4.4 shows that in response to a positive aggregate technology shock, in both the open and closed economy, firms with lower firm-level productivity, who would otherwise be unable to enter the market, enter the market, decreasing in the first instance average domestic firm-level productivity, $\tilde{z}_D^h$. However, as the new firms enter the market, N_E^h, driven by potentially higher profits, the relatively less productive firms are forced out of the market, due to the increased competition in the market and average domestic firm-level productivity then increases. The positive aggregate technology shock also increases the real wage, w^h, leading firms to increase their prices, thus leading to a reduction in demand. The real wage increase leads to a rise in the fixed entry cost and the fixed cost of domestic production (measured in effective labour units). These higher costs mean that when firms are hit by the exogenous death shock, new firms do not enter the market to replace them, and thus, average firm-level productivity falls back to its initial steady state, albeit at a slower rate than the aggregate technology level. However, in the open economy, the later persistence of productivity is higher than in the closed economy, driven by a larger increase in the number of entrants and hence a larger increase in the number of domestic firms. The larger number of

entrants in the open economy is caused by the increase in the competitiveness of domestic exporters in foreign markets, driven by the increase in domestic aggregate technology. The spike in technology not only increases domestic profits, but also the profits from exporting, thus more firms enter the market to take advantage of the increased total profits. The larger increase in the number of domestic firms leads to an increase in domestic wages, as competition for labour increases, causing the number of new entrants to fall. This explains the higher persistence of productivity in the open economy after around period 22. Our results are consistent with the empirical findings of Moreira (2017) and Sedlacek and Stern (2017), that the entry and exit of less productive firms into the market can drive a persistent response of labour productivity to macroeconomic shocks.

Figure 4.5: Response to Transitory Shock to the Sunk Cost of Entry (f_E^h)

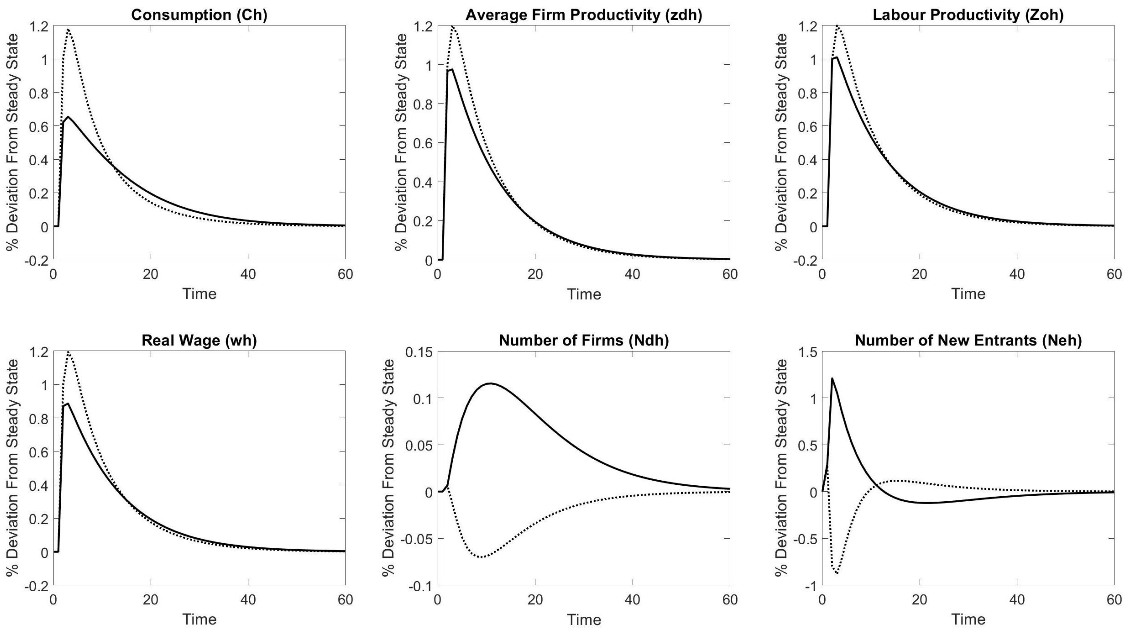
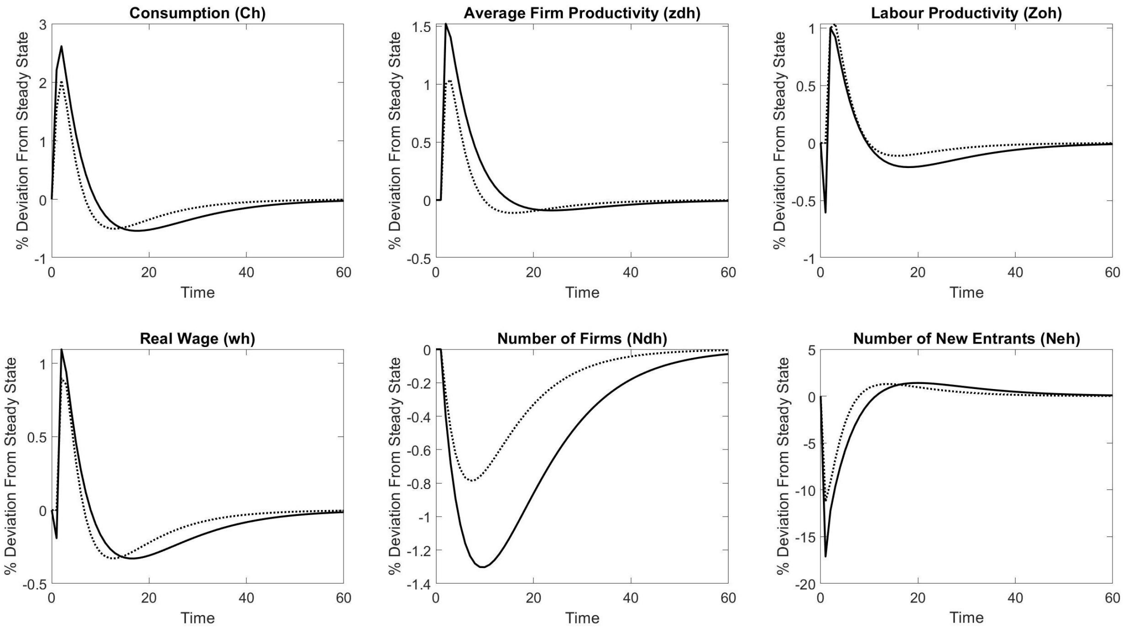


Figure 4.5 presents the response paths of the same macroeconomic variables as Figure 4.4 to a negative transitory shock to the sunk cost of entry in both the open and closed economies. Comparing to the case of the aggregate technology shocks, the response paths now appear less smooth, as a change in the sunk cost of entry predominantly impacts new firms entering the market, and existing firms only indirectly, through changes in the real wage. Given its low impact on existing firms,

a decrease in the sunk cost of entry leads to a lower increase in productivity, shown by the larger shock size needed for a 1% increase in productivity. A reduction in the sunk entry cost in the open economy (temporarily) allows new firms to enter the market, N_E^h, and drives up the real wage, w^h, which causes less productive firms to become unprofitable and exit the market, thus driving up both firm-level productivity, $\tilde{z}_D^h$, and labour productivity, Z_O^h. However, as the sunk cost of entry returns to its pre-shock value, the number of new entrants decreases, as firms are hit by the exogenous death shock. The real wage therefore returns to its initial steady-state level, as do productivity and consumption, C^h. The rate at which productivity and consumption return to steady state is lower than the rate at which the shock dissipates due to the increase in the number of domestic firms, which leads to increased competition in the domestic market, which, in turn, drives up productivity temporarily. It is only as the number of firms returns to its steady-state level that the average firm-level productivity also returns to steady state. In the closed economy the response of productivity is similar, although the driving forces are slightly different. In response to the decrease in the sunk costs of entry, more firms attempt to enter the economy, thus driving up the wage rate, as more labour is required to pay the sunk costs of entry. The increase in the wage rate drives up the cutoff productivity for domestic production, as firms now face higher fixed costs of domestic production (denominated in effective labour units) and higher wage costs. Given that the number of successful entrants into the market is dependent on the probability of drawing a productivity higher than the cutoff level, the increase in the cutoff level means that although more labour is being used to pay the sunk costs of entry, the number of successful entrants into the market decreases, as more firms now draw a productivity below the threshold level, and thus exit the market immediately. As the shock dissipates, and thus the number of firms attempting to enter the market decreases, so does the wage rate and therefore the average domestic firm productivity as well.

Figure 4.6 presents the response paths of the same macroeconomic variables as Figures 4.4 and 4.5 to a positive transitory shock to the fixed costs of domestic

Figure 4.6: Response to Transitory Shock to the Fixed Cost of Domestic Production (f_D^h)



production in both the open and closed economies. When the shock to the fixed costs hits, relatively less productive firms are no longer able to make profits, and exit the market, N_E^h, thus leading to an increasing average firm productivity, $\tilde{z}_D^h$, in the period immediately after the shock. As a result of higher productivity, firms are able to pay a higher real wage, w^h, and also make higher profits. The higher real wage and higher profits are passed onto households leading to higher consumption, C^h. The increase in fixed costs also means that less productive firms are no longer able to make sufficient profits to pay back their sunk costs of entry, so they do not enter the market, thus further increasing productivity. However, as the shock dissipates, and the number of firms returns to equilibrium, the competition in the market decreases, due to a lower number of firms in the market, N_D^h. This leads to a higher number of relatively less productive firms to quickly enter the market, dragging down average firm-level productivity and causing labour productivity to dip below its original steady-state level before returning to equilibrium. Given that the competition on the domestic market is larger in the open economy due to competition from imports, the increase in the fixed costs of domestic production cause a larger number of unproductive firms to exit the market in the open economy compared to the closed economy, resulting in a much less persistent response of productivity to such a shock in the open economy.

In this section we have examined the impact of the entry and exit of less productive non-trading firms into the market on the persistence of the response of labour productivity to different macroeconomic shocks, in order to provide a possible explanation for the wide variation in empirically calculated figures for labour productivity persistence. We have shown that the entry and exit of less productive non-trading firms into the market introduces an endogeneity into this persistence, and allows the response of productivity to aggregate technology and sunk costs of entry shocks to be more persistent than the shocks themselves. At the same time, we showed that the response of productivity to a shock to the fixed costs of domestic production is less persistent than the shocks themselves. Therefore, it is possible that when the empirically calculated persistence of productivity is lower, as in Pancrazi and Vukotic (2011), this may be because the shock driving the response of productivity was acting on the fixed costs of domestic productivity, while larger persistence, such as that found in Baxter (1995), may be because the shock driving the response of productivity was acting on the aggregate technology levels of firms.

4.4.2 Import and Export Cost Shocks

In this section we seek to examine whether changes in barriers to imports or exports have a greater impact on productivity. As mentioned earlier, intuitively, given that barrier to import changes directly affect all firms in the economy, while barrier to export changes directly affect only trading firms, barrier to import changes would have a larger impact on productivity. However, existing models such as Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014) are not able to replicate this result, and barrier to export changes have a much larger impact on productivity. The introduction of the entry and exit of less productive non-trading firms into the domestic market allows imports to affect the average productivity of non-trading firms directly, and therefore may generate a larger response of labour productivity to barriers to imports. To fully explore the relative impact of barriers to imports and exports in driving the entry and exit of less productive non-trading domestic firms (and thus productivity), we analyse the dynamic responses of labour productivity to transitory shocks of the same magnitude to changes in barriers to imports and barriers to exports broken down between shocks to the variable and fixed costs of trade. We assume that the shocks follow AR(1) processes similar to the previous transitory shocks.

In Figure 4.7 we present the response of labour productivity to a one period, 1 percentage point negative shock to the iceberg costs of importing, τ_h^i, and τ_h^j, shown by the solid line, and a one period, 1 percentage point negative shock to the iceberg costs of exporting, τ_i^h, and τ_j^h, shown by the dotted line. In Figure 4.8 we present the response of labour productivity to a one period, 1 percentage point negative shock to the fixed costs of importing, f_{Xh}^i and f_{Xh}^j, shown by the solid line and a one period, 1 percentage point negative shock to the fixed costs of exporting, f_{Xi}^h and f_{Xj}^h, shown by the dotted line.

Figure 4.7: Response of Labour Productivity to Transitory Shocks to the Iceberg Costs of Trade

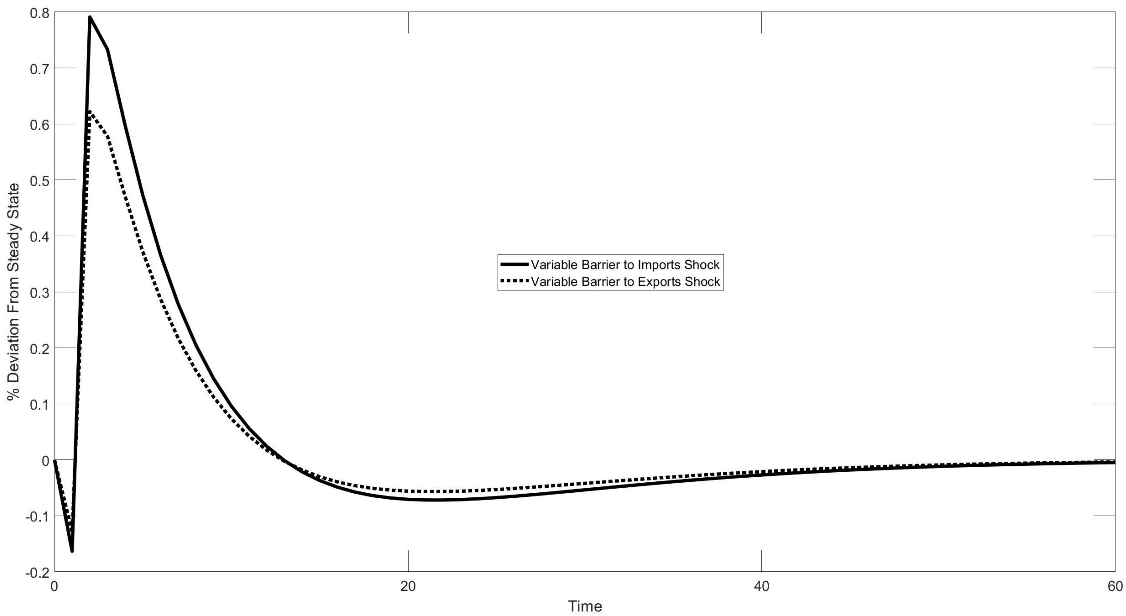
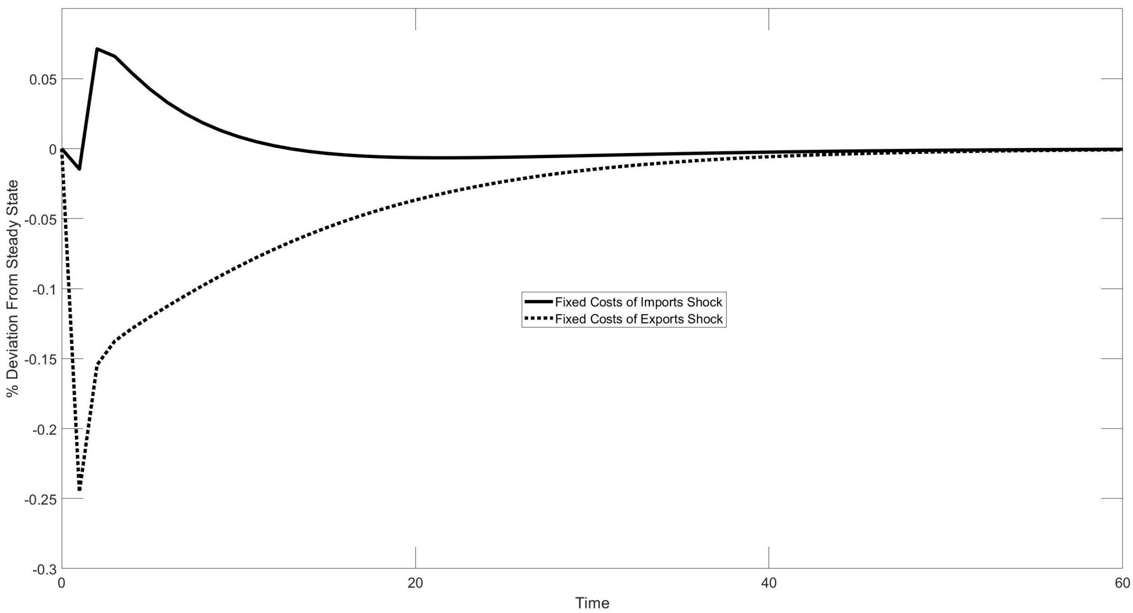


Figure 4.7 shows that a shock to the variable costs of importing induces a larger

Figure 4.8: Response of Labour Productivity to Transitory Shocks to the Fixed Costs of Trade

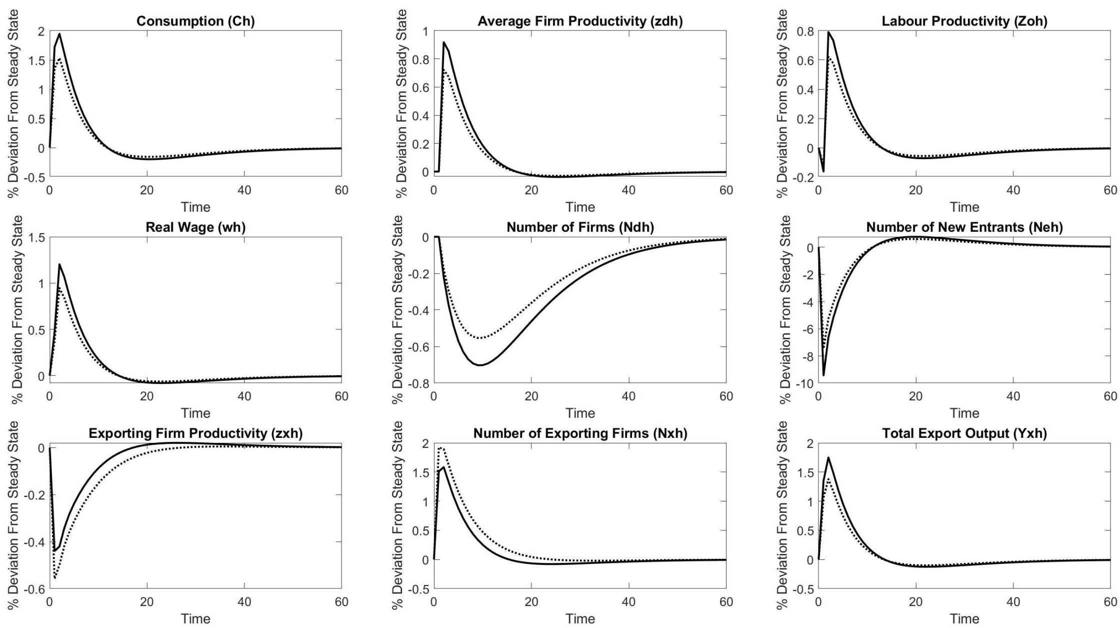


impact on labour productivity, 0.79% above the initial steady state, than a shock of the same magnitude to the variable costs of exporting, about 0.62% above the initial steady state.[9] Figure 4.8 shows a slightly different result to Figure 4.7. As in the case of shocks to the variable cost of trade, a shock to an importing cost, in this case the per period costs of exporting to the UK (UK imports), induces an increase in UK productivity, albeit to a more limited extent than a variable cost of importing shock, 0.07% above the initial steady state. However, a shock to the per period costs of exporting from the UK induces a reduction in UK productivity of 0.25%. These results can be explained by the ways in which different types of firms are impacted by trade costs. Our result that a reduction in barriers to imports lead to an increase in productivity is consistent with the existing empirical literature, see for example Amiti and Konings (2007), Yasar and Paul (2007) and Bloom *et al.* (2016).

[9]We show that this result is invariant to country size. As the size of the domestic economy increases relative to the size of the other countries, the magnitude of the response of labour productivity to trade barrier shocks diminishes, however the response to import barrier changes remains higher than the response to export barrier changes.

To further examine the driving mechanisms behind these results Figures 4.9 and 4.10 present the response path of consumption, C^h, average productivity for domestic production, $\tilde{z}_D^h$, labour productivity, Z_O^h, the real wage, w^h, the number of firms, N_D^h, the number of new entrants, N_E^h, the average firm productivity of exporters to the EU[10], z_{Xi}^h, the number of exporters to the EU, N_{Xi}^h, and the total output for exporting to the EU, Y_{Xi}^h, to the one period transitory shocks presented above. The solid lines plot the response to the shocks to the barriers to imports, while the dotted lines plot the response to the shocks to the barriers to exports.

Figure 4.9: Breakdown of the Response to Transitory Shocks to the Iceberg Costs of Trade



As the variable cost of imports decrease, the amount of competition from imports increases too, as the domestic market becomes more attractive to foreign exporters. As competition increases, less productive non-trading firms, who are impacted by competition from imports, are no longer able to make profits and thus exit the market, driving up both firm-level productivity, $\tilde{z}_D^h$, and labour productivity, Z_O^h, significantly, as Figure 4.9 shows. As the less productive firms exit the market,

[10]Note that the responses of the average firm productivity, number of and output for exports to the RoW are almost identical for those for exports to the EU

causing decreases in the number of firms, N_D^h, the competition for inputs decreases, which allows less productive firms to re-enter the market, causing productivity to quickly drop, and even dip below its initial steady-state level, as was also seen in the case of a transitory shock to the fixed costs of domestic production, presented in section 4.4.1.

Changes in the variable cost of exporting meanwhile significantly impact the domestic firms that engage in international trade (export); however, these firms make up a relatively small proportion of the total number of domestic firms (less than 1% of US firms according to the 2016 Census). On the other hand, non-trading domestic firms make up the majority of firms and are only directly impacted by changes in barriers to exports through changes in the competition for inputs, which, in our model, is competition for labour[11], reflected in the wage rate, w^h. The decrease in the variable cost of exporting impacts both the number of exporting firms, N_{Xi}^h, (the extensive margin of trade) and the total output for exporting, Y_{Xi}^h (intensive margin of trade), both of which increase after the variable cost of exporting decreases.

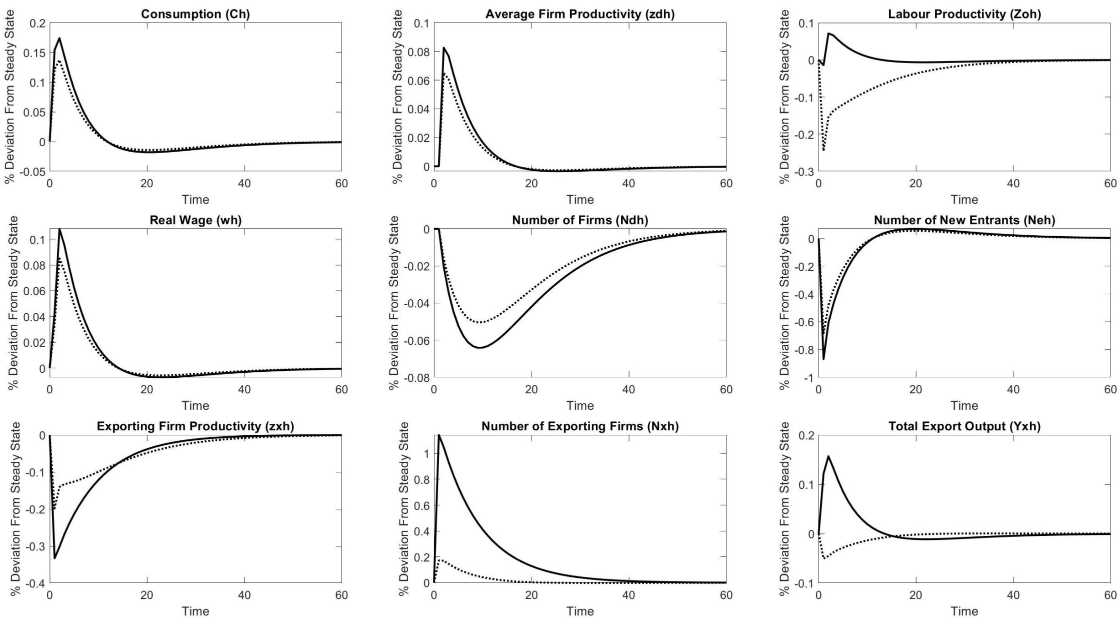
When variable costs of exporting decrease, competition for inputs and, to a lesser extent, competition from importers will change, and affect productivity in the same direction: exporting firms demand additional labour to serve international markets, and this drives up the real wage which forces the least productive non-trading firms to exit, thus increasing average productivity. Additionally, competition from importers will further increase labour productivity but only through general equilibrium effects on exporters in foreign countries. As in the case of changes in barriers to imports, as the less productive firms exit the market, the competition for inputs decreases, allowing less productive firms to re-enter the market, causing productivity to quickly decrease, and even dip below its initial

[11]In addition, changes in barriers to exports will indirectly change competition from imports through general equilibrium effects on foreign countries, but the impact of this change in competition is small.

steady-state level.

Given that the impact of an increase in competition from imports has a greater impact on non-trading firms than increased competition for inputs because non-trading firms are directly impacted by changes in competition from imports, but only indirectly impacted by changes in competition for inputs, the impact of changes in barriers to imports on productivity is greater than the impact of changes in barriers to exports, consistent with the empirical literature, such as Bloom *et al.* (2016).

Figure 4.10: Breakdown of the Response to Transitory Shocks to the Fixed Costs of Trade



As Figure 4.10 shows, the impact of a reduction in the fixed costs of importing causes an almost identical response to a decrease in the variable cost of importing, albeit of a smaller magnitude. In both cases, the competition from imports increase, driving less productive firms out of the market, leading to a decrease in the number of firms, N_D^h, and increasing both firm-level productivity $\tilde{z}_D^h$ and labour productivity Z_O^h. As the shock dissipates, the competition from imports returns to steady state and thus the number of domestic firms also returns to equilibrium. As the number of firms returns to equilibrium, the competition for labour also intensifies, causing productivity to also return to its steady-state level.

The impact of a reduction in the fixed costs of exporting on the other hand, leads to a significantly different response of productivity. In this case, labour productivity decreases, before slowly returning to equilibrium as the shock dissipates. As the fixed cost of exporting decreases, less productive firms are able to enter the exporting markets, as a result of the decrease in the cutoff productivity for exporting. The number of exporting firms then increases, and thus so does the number of units of labour needed to pay for the fixed costs of exporting, causing an increase in the real wage, w^h. As firms set their price equal to a fixed mark-up over marginal cost, the combination of increased wage costs and decreased average productivity of exporters causes the average price of exports to increase, decreasing foreign demand, and leading to a decrease in the number of units of output that are sold in domestic markets, even if the total value of exports increases. Thus, although the number of exporting firms, N^h_{Xi}, increases (the extensive margin of trade) the total output per firm, Y^h_{Xi}, decreases (intensive margin of trade), leading to a reduction in the total number of export units sold. Given that the labour used in production (the labour force less the labour used in the sunk cost of entry) increases as a result of the reduction in the number of new entrants, and that the number of units of output produced for export markets decreases, labour productivity, measured as output per hour falls.

In this section we examined which of changes in barriers to imports or changes in barriers exports have a greater impact on productivity. We showed that, once we allow for the entry and exit of less productive non-trading firms into the domestic market changes in barrier to imports have a larger impact of labour productivity than changes in barriers to exports of the same magnitude. Existing models such as Ghironi and Melitz (2005) and Fattel Jaef and Lopez (2014) are not able to replicate this result, as in these models changes in barriers to imports only affect the allocation of labour between trading and non-trading firms, rather than causing endogenous changes in the average productivity of domestic firms.

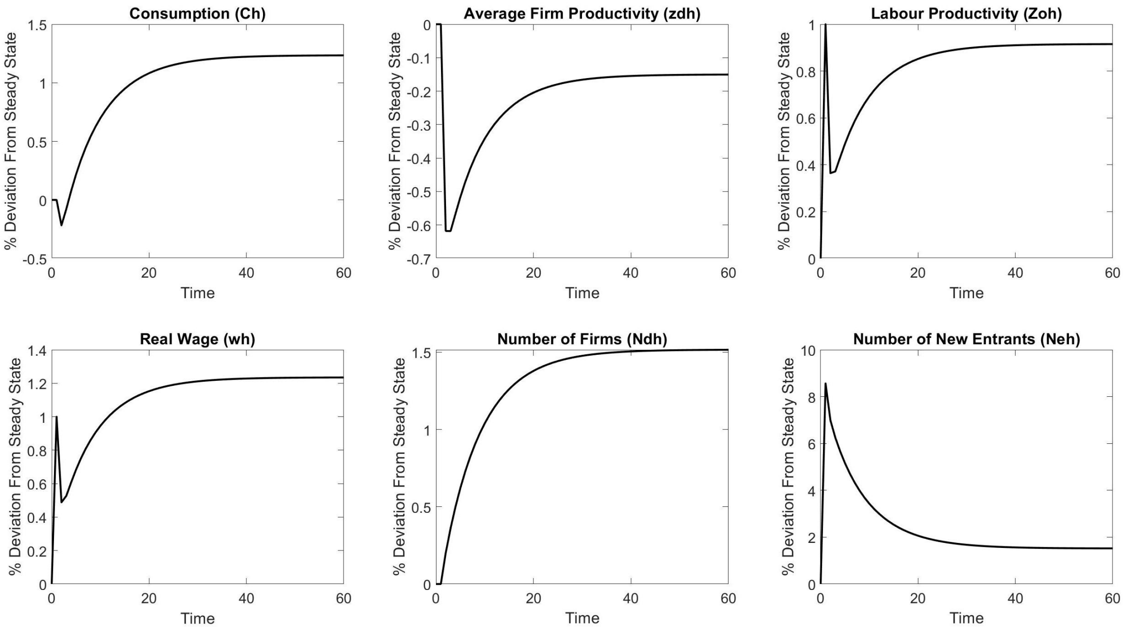
4.4.3 Permanent Shocks

This section analyses how the entry and exit of less productive non-trading firms affects the response of the economy to permanent macroeconomic shocks, by comparing the response in our framework to the responses in the baseline Ghironi and Melitz (2005) framework, where the productivity distribution is exogenously fixed. For this comparison, we examine the dynamic response of consumption, C^h, average firm productivity, $\tilde{z}_D^h$, labour productivity, Z_O^h, the real wage, w^h, the number of firms, N_D^h, and the number of new entrants, N_E^h, to three separate permanent macroeconomic shocks in country h: first, a permanent 1% increase in aggregate, Z^h; second, a permanent 1% decrease in the sunk cost of entry f_E^h; third, a permanent 1% increase in the fixed cost of domestic production, f_D^h.

Figure 4.11 shows the dynamic response of consumption, C^h, average firm productivity, $\tilde{z}_D^h$, labour productivity, Z_O^h, the real wage, w^h, the number of firms, N_D^h, and the number of new entrants, N_E^h, to a permanent 1% increase in aggregate technology in country h. The increase in aggregate technology allows the relatively less productive firms, previously unable to make profits, to immediately enter the market, sharply increasing the number of new entrants, and driving down average firm-level productivity and leading to an increase in the number of firms. However, the decrease in average firm-level productivity is not as large as the increase in aggregate technology (0.6% in the short run and 0.18% in the long run, compared to an 1% increase in aggregate technology), therefore labour productivity increases. The increase in labour productivity allows firms to pay a higher real wage, and make higher profits, leading to an increase in consumption. As the real wage increases, the less productive firms who initially entered the market are no longer able to pay the higher real wage and exit the market, allowing firm-level productivity to return slowly to its new, lower, steady-state level.

The endogenisation of the distribution of firm productivity in our model introduces a smoothing effect to the behaviour of the endogenous variables, such as consumption and the real wage, as these variables move more gradually to their new steady-state

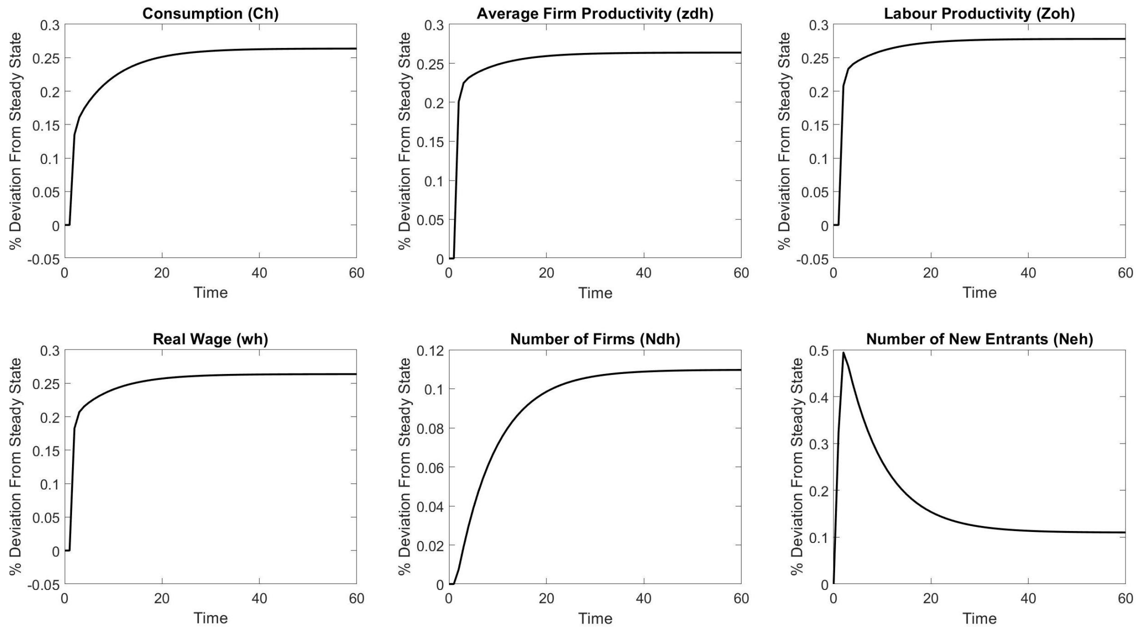
Figure 4.11: Response to a Permanent Increase in Aggregate Technology(Z^h)



level in our model than in the case in which the distribution of firm productivity is fixed, as in Ghironi and Melitz (2005). In our model, consumption does not jump immediately to a higher level as in Ghironi and Melitz (2005), but moves gradually to its new steady state, driven by the entry and subsequent exit of less productive firms, matching more closely the seasonally adjusted US GDP in the World Bank data. A similar behaviour is observed when examining the other endogenous variables, such as the real wage, the number of new entrants, and the number of domestic firms: the response of these variables in our model is much smoother than of those observed when the distribution of firm productivity is fixed.

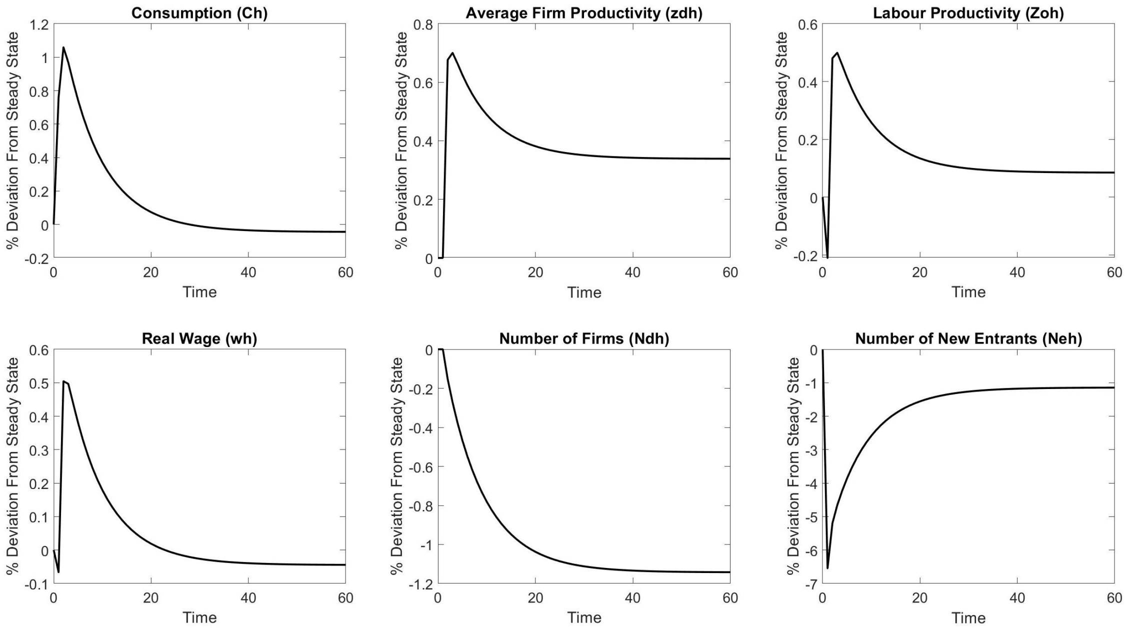
Figure 4.12 shows the dynamic response of consumption, average firm productivity, labour productivity, the real wage, the number of firms and the number of new entrants to a permanent 1% decrease in sunk entry costs in country h. The decrease in the sunk entry costs allows a large number of new productive firms to immediately enter the market, increasing sharply the number of new entrants, N_E^h. The increased competition for inputs from the new productive firms drives the relatively less productive firms out of the market, thus increasing average firm-level productivity, $\tilde{z}_D^h$. As in the case of the permanent increase in aggregate technology, the increase in productivity allows firms to pay a higher real wage, w^h, and make higher profits, leading to an increase in consumption, C^h. After the initial sharp increase in labour productivity, as more productive firms slowly enter the market, the relatively less productive firms are driven out by the increased competition for inputs, and thus consumption, C^h, labour productivity, Z^h_O, and the real wage, w^h, slowly increase to their new, higher steady-state levels.

Figure 4.12: Response to a Permanent Decrease in Sunk Costs of Entry (f^h_E)



The introduction of endogenous firm-level productivity in our model has the effect of counteracting the initial consumption undershooting in Ghironi and Melitz (2005). In contrast to their model, consumption in our model raises sharply, before increasing slowly to its new higher steady-state level, driven by the sudden exit of unproductive firms from the market, giving the movement/change in the cutoff productivity level for domestic production. As in the case of the transitory shock, the decrease in sunk entry costs immediately drives up the real wage as new firms enter the market, as well as increasing average firm-level productivity, both of which increase consumption. As more firms enter the market, this effect continues, albeit at a decreasing rate, as the economy moves towards the new steady state.

Figure 4.13: Response to a Permanent Increase in Fixed Costs of Domestic Production (f_D^h)



In contrast to the dynamic responses to permanent shocks to aggregate technology and the sunk costs of entry, a permanent shock to the fixed cost of domestic production can induce significant overshooting of the endogenous variables. In Figure 4.13 we present the dynamic response of consumption, average firm productivity, labour productivity, the real wage, the number of firms and the number of new entrants to a permanent 1% increase in the fixed cost of domestic production in country h. A permanent increase in the fixed cost of domestic production induces consumption, the real wage, labour productivity and the number of new entrants to overshoot sharply their new steady-state levels before slowly returning to their new equilibrium levels. The increase in fixed costs of domestic production drives the relatively less productive firms out of the market immediately, as they are no longer profitable, leading to an immediate increase in average firm productivity. The increase in fixed costs of domestic production also leads to a sharp fall in the number of new entrants, N_E^h, as the least productive firms, previously able to enter the market and make profits, are no longer able to enter. The exit of the least productive firms from the market decreases competition for inputs, and allows the relatively less productive firms to slowly enter the market, driving labour productivity down to its new, higher steady-state level.

Thus, productivity overshoots its new steady-state level initially, before slowly falling as the competition for inputs decreases. Similar to the permanent increase in aggregate technology and the permanent decrease in the sunk cost of entry, the increase in firm-level productivity allows firms to pay a higher real wage, w^h, and make higher profits, which sharply increases consumption, C^h. However, as (more) new firms enter the market, productivity moves towards its new equilibrium level, leading the real wage and consumption to fall back to their new, lower steady-state levels.

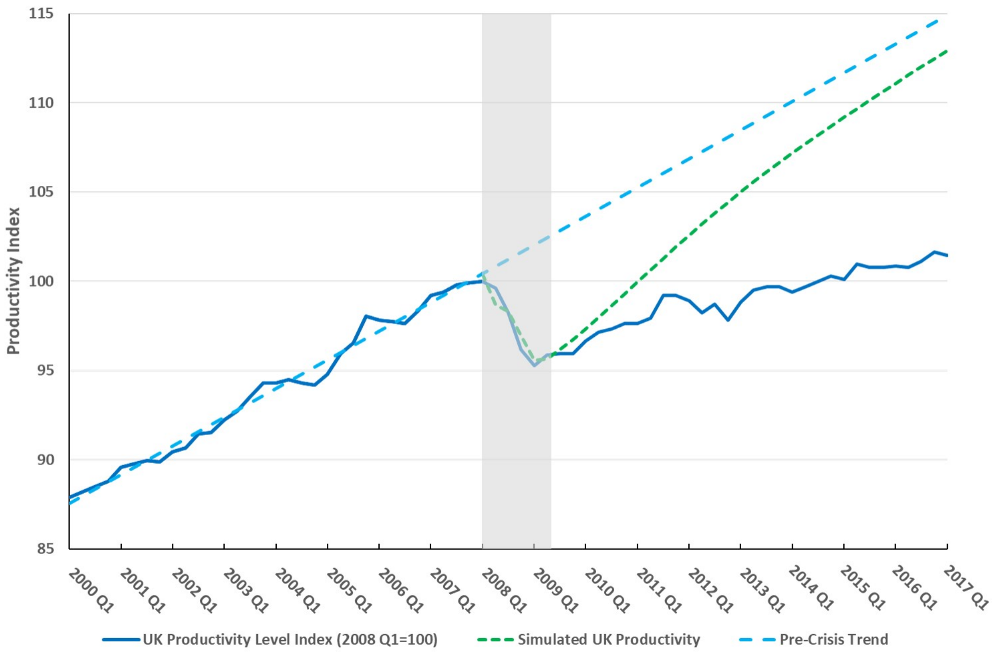
In this section we analysed how the entry and exit of less productive non-trading firms affects the response of the economy to permanent macroeconomic shocks, by comparing the response in our framework to the responses in the baseline Ghironi and Melitz (2005) framework, where the productivity distribution is exogenously fixed. We showed that our model generates smoother responses to permanent shocks to technology and the sunk costs of entry, which better reflects movements in seasonally adjusted US GDP data from the World Bank.

4.5 UK Productivity Puzzle

Since 2008, productivity in the UK has stagnated to such an extent that in 2017 Q4, it was 16% lower than the continuation of its pre-crisis trend would predict (measured as output per employed worker). In Figure 4.14, the solid (dark blue) line plots quarterly UK productivity and the dashed (light blue) line plots its pre-crisis trend.

The decline and the subsequent stagnation in UK productivity could have been driven by two factors: 1) business responses to a reduction in consumer demand, leading to a temporary drop in productivity; 2) more persistent supply-side factors, such as a reduction in investment in research and development (see for example Millard and Nicolae (2014)) or changing credit conditions (see for example Franklin *et al.* (2015)), leading to a permanent decrease in UK productivity growth.

Figure 4.14: UK Labour Productivity



In the first case, the reduction in consumer demand may have led to labour hoarding by businesses, as Patterson (2012) and Martin and Rowthorn (2012) argue or, according to Goodridge *et al.* (2013*a*) and King and Millard (2014), to higher investment in intangible assets. Both labour hoarding and higher investment in intangible assets would cease once consumer demand recovered, allowing productivity to start returning to pre-crisis levels. In the case of the more persistent supply-side factors, the number of firms with relatively low productivity may have permanently increased causing a permanent drop in average UK labour productivity. Franklin *et al.* (2015) note that after the Great Recession, in the UK, the supply of credit decreased, particularly for firms entering the market, allowing less productive firms to survive due to lower competition. The decrease in the supply of credit was also examined by Corry *et al.* (2011), who noted the lower firm creation rates in the UK after Great Recession, which they explained by the decreased availability of loans to new businesses, as a result of financial institutions increased internal capital requirements. Similar constraints on UK firm credit post Great Recession were found by Saleheen *et al.* (2017) in their survey of UK businesses, and by Chadha *et al.* (2017) in their examination of the sectoral differences of UK productivity.

In addition to examining the credit restrictions UK firms faced after the Great Recession, the recent UK Productivity Puzzle literature also examines the impact of lower debt servicing costs on UK productivity. Arrowsmith *et al.* (2013) examine the extent to which bank forbearance and low interest rates have led to increased firm survival. They argue that although the extent to which bank forbearance affected UK productivity is small, low interest rates made debt servicing costs lower which had a large effect on UK productivity. The link between the debt burden of a firm, driven by the interest burden, and firm survival in the UK was also examined by Guariglia *et al.* (2016), who concluded that there was a statistically significant link between the interest burden of a firm and their survival rate during the Financial Crisis and Great Recession. Given that the interest burden decreased post Great Recession, it can be argued that firm survival rates increased, leading to lower productivity growth.

In this chapter we examine the effect of both a reduction in consumer demand and of (more) persistent supply-side factors such as changing credit conditions, captured here by a reduction in the supply of credit for firms entering the market and by a lower debt servicing cost for existing firms (driven by lower interest payments) on labour productivity in the UK since the Financial Crisis/Great Recession, in order to gauge the extent to which they could explain the UK Productivity Puzzle.

The reduction in consumer demand, driven by the Financial Crisis and subsequently by the Great Recession, is simulated as a temporary shock to aggregate technology in all three countries, matching the magnitude of the decrease in productivity in the UK, the EU and the RoW. The reduction in the supply of credit for firms entering the market is simulated as a permanent positive shock to the sunk cost of entry. The reduction in the debt servicing cost is simulated as a permanent negative shock to the per-period fixed cost of domestic production. We run simultaneously through our model the three shocks, which are calibrated for this exercise as follows:

1. To simulate the reduction in consumer demand driven by the Financial Crisis and subsequently by the Great Recession in the UK, the EU and the RoW, per-period shocks to aggregate technology (Z_t^h, Z_t^h and Z_t^h) of -0.011, -0.008 and 0.00025 respectively, are run for 4 periods, to match the reductions in productivity according to the OECD data.

2. After the Great Recession, in the UK, the credit supplied by the financial sector to the domestic market decreased by 22% from 2008 to 2015.[12][13] Approximately 25% of a new start-up cost is related to setting up a company, including the costs associated with obtaining credit. If all company's start-up costs were directly linked to the supply of credit, the increase in f_E^h would be 5.5% (22% times 25%). However, given that not all start-up costs are directly related to domestic credit, for a more accurate calibration for a more realistic simulation exercise, f_E^h is only increased by 4% relative to its pre-crisis level. To match the timing in the data, we assume that f_E^h increased by 0.166% in each of the first 24 periods.

3. The average interest paid by the UK companies registered with the Bureau Van Dijk Orbis database, decreased over 2008-2015 by 4%, in nominal terms. In real terms, however, the reduction was substantially larger: 20.2%. Over the same time period, the average interest paid (as a proportion of total fixed cost was) 10.5%. To simulate the impact of the reduction in the UK interest rate, and its effect on the debt servicing cost, the fixed cost of domestic production in the UK, f_D^h, is reduced by 2.1% (20.2% times 10.5%) relative to the pre-crisis level. To match the timing of the reductions in the UK interest rate, f_D^h is decreased by 0.5% in each of the first 4 periods, and by 0.1% in period 5.[14]

The dashed green line in Figure 4.14 plots the simulated UK labour productivity according to our model, when simultaneously running through the model the

[12]According to World Bank data on credit supplied by the UK financial sector to the domestic market from the start of the Great Recession to 2017.

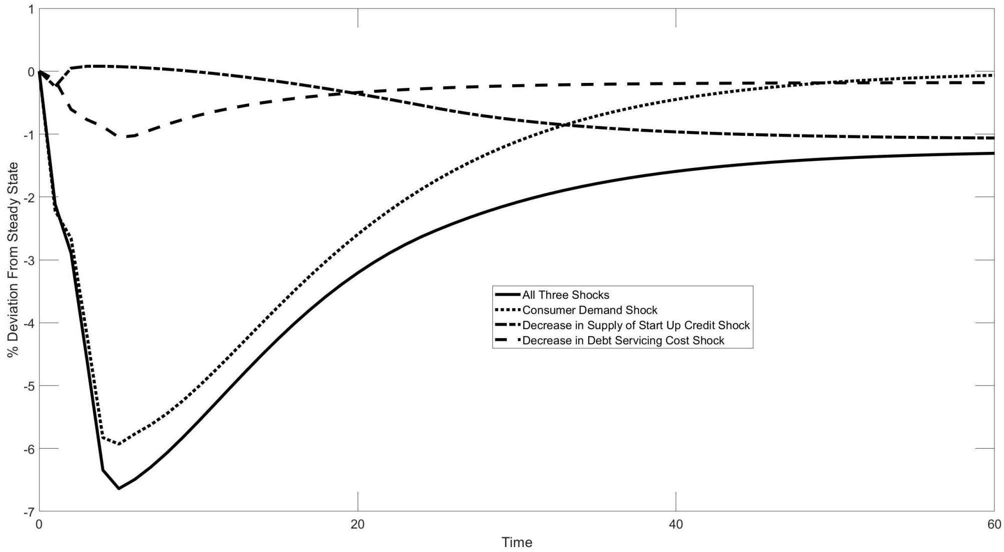
[13]From 210% of GDP in 2008 to 163% of GDP in 2015.

[14]the Bank of England took approximate 1 year and one quarter to reduce the interest rate to its post-crisis level.

shocks presented above. We note that it matches the data quite well in the periods immediately following the Financial Crisis. The initial drop in the level of productivity according to the results of our simulation is 6.43% relative to pre-crisis trend, while according the data this is 6.45%. Up to 2011 Q3, simulated productivity successfully replicates the behaviour of UK productivity, when it explains about 4.3% points of the 6.4% shortfall of the UK productivity relative to a continuation of its pre-crisis trend, illustrating the role entry and exit of relatively less productive non-trading domestic firms into the domestic market can have on aggregate productivity. However, the slowdown in growth after 2011 Q3 cannot be accounted for. Our result shows that in response to a 4% increase in the sunk entry cost and a 2.1% reduction in per-period fixed cost of domestic production in the UK relative to their pre-crisis levels, UK labour productivity is expected to decrease in the long run by 1.22%, while the shortfall of UK productivity from the continuation of its pre-crisis trend kept increasing to be 16% in 2017 Q4. The results of our simulation indicate that changes in credit conditions (as captured here) can explain a small but significant part of this shortfall. Our calculations show that of the 1.99% long-run decrease in UK productivity, approximately 1% is attributable to the increase in firm start-up costs, and approximately 0.22% is attributable to decreased debt servicing cost for existing firms. If the firm set-up costs were entirely dependent on the supply of credit, and therefore the start-up costs increased by 5.5% after the Great Recession, then the long-run decrease in UK productivity attributable to increased start-up costs becomes larger, from 1% to 1.4%.

An analysis of the effect of each of the shocks on labour productivity, reveals that in response to a temporary negative consumer demand shock, labour productivity decreases to almost 5.4% below its initial steady-state level, as shown by the dotted line in Figure 4.15. This shows that if the reduction in UK labour productivity was solely caused by declining consumer demand, then UK productivity would have returned to its initial steady-state level within

Figure 4.15: The Effect of Individual Shocks on Labour Productivity



approximately 10 years with no permanent effect.

On the other hand, the response of labour productivity to a permanent positive start-up credit supply shock, shown by the dotted line, is to never recover to its initial steady-state level, reaching its new long run steady-state level which is 1% below the initial one soon after approximately 10 years. Labour productivity will first slightly increase, as a result of increased demand for labour which drives up the real wage following the increase in the sunk cost (as the fixed/sunk costs are expressed in labour unit terms), leading relatively less productive (non-trading) firms to exit the market. But as this happens, labour productivity decreases, as competition in the UK market decreases following the increase in the start-up costs, allowing unproductive firms to remain in the market, while exiting firms are not replaced at the same rate as before because of the higher start-up costs, permanently decreasing productivity.

Similarly, the response of labour productivity to a permanent negative debt servicing cost shock, as shown by the dashed line, is to permanently lower average productivity to 0.22% below the initial steady-state level. This is as the effect of lower interest payments on existing debt is to decrease the cost of staying in the market, allowing relatively less productive (non-trading) firms to stay and/or enter the market and make profits. Short term, the effect of a reduction in interest payments (through its effect on the debt servicing cost) on labour productivity is more pronounced, immediately following the lower cost of staying in the market, lowering average productivity to up to 1% below the initial steady state.

These results do not provide an explanation for the increasing shortfall of the UK productivity relative to a continuation of its pre-crisis trend, driven by lower trend productivity growth post crisis, but do provide an explanation as to why this shortfall is non-zero i.e. why the level of productivity has fallen.

We argue that changes in credit conditions in the UK following the Financial Crisis led to a higher number of relatively less productive firms entering the UK market, which - unlike in existing models - is captured and driven in our model by an endogenous average firm-level productivity, as the firm-level productivity distribution changes. However, our model shows that changes in credit conditions cannot fully explain the magnitude of the UK Productivity Puzzle. Franklin *et al.* (2015) show that 5-8% of the UK productivity decline up to 2014, could be explained by reductions in UK credit supply, while our model suggests that only 1.22% could be explained by such reductions. In Franklin *et al.* (2015) the decline of UK labour productivity is explained by the substitution of capital with more labour-intensive methods of production caused by the increased cost of capital. Given that we do not model capital in our model, the degree to which changes in credit conditions, as captured in our chapter, can contribute to our understanding of the UK Productivity Puzzle is not surprising.

4.6 Conclusion

In this chapter we have developed a three-country dynamic, stochastic, general equilibrium macroeconomic model of international trade with monopolistic competition and heterogeneous firms, in order to explore the role of the entry and exit into the domestic market of less productive non-trading domestic firms on labour productivity and its persistence in response to shocks to macroeconomic variables. Unlike the existing literature, we allow for the distribution of firm-level productivity to be endogenously determined in our model through the entry and exit of less productive non-trading firms into the domestic market, and we run our analysis in a three-country world. Two main results stand out from our study:

First, unlike in the existing theoretical literature such as Ghironi and Melitz (2005), we show that changes in barriers to imports have a much larger effect on domestic productivity than changes in barriers to exports of an equivalent size. In this existing theoretical literature, labour productivity can only change as a result of changes in the number of domestic firms (the extensive margin of production). In our model we allow for changes in the extensive as well as intensive margins of production, through endogenous changes in both the number of domestic firms and the productivity distribution of producing firms. Our results show the key role of the entry and exit of less productive non-trading firms into the domestic market in driving productivity, a result which is consistent with empirical papers such as Yasar and Paul (2007) and Bloom *et al.* (2016).

Second, the entry and exit of less productive non-trading domestic firms into the domestic market can explain the persistence of labour productivity in response to transitory macroeconomic shocks. We show that the persistence of labour productivity in response to transitory shocks to aggregate technology and the sunk cost of entry is higher than the exogenous persistence of the two shocks, but the persistence of labour productivity in response to transitory shocks to fixed costs of domestic production is lower than the exogenous persistence of the shock, irrespective of the calibration of the persistence of the shock. Therefore, we offer a potential explanation for the wide variation in the empirically calculated figures for the persistence of productivity from 0.85 in Pancrazi and Vukotic (2011) to 0.906 in Backus *et al.* (1992) and 0.994 in Baxter (1995).

We also use our model to examine the extent to which changes in credit conditions seen in the UK shortly after the Financial Crisis/Great Recession could contribute to our understanding of the UK Productivity Puzzle. We show that our model can successfully replicate the behaviour of UK productivity for the first three and a half years after the Great Recession. We conclude that changes in consumer demand and credit conditions can account for about 4.3% points of the 6.4% shortfall of the UK productivity in 2011 Q3 relative to a continuation of its pre-crisis trend, illustrating the role entry and exit of relatively less productive non-trading domestic firms into the domestic market can have on aggregate productivity. The non-trading domestic firms are both the most unproductive firms and most numerous and therefore small credit changes can have significant effects on the entry and exit of these firms, leading to large changes in aggregate productivity.

Future research might investigate the role of non-trading firms' exit and entry into the domestic market in driving labour productivity and its persistence, in a context in which two current restrictive assumptions in the model are relaxed: 1) trade balances in every period; and 2) full employment. Relaxing the first assumption would allow us to account for the intertemporal consumption smoothing allowed by international trade (Obstfeld and Rogoff (1995)). Relaxing the assumption of full employment would allow us to examine the relationships between trade, firm entry and exit, job creation and destruction, productivity and the unemployment rate.

Chapter 5

Is Ricardo Still Relevant? An Empirical Re-examination of Ricardian Trade Theory

5.1 Introduction

Ricardian Trade Theory predicts that countries will specialise, produce and export in the industries in which they have a comparative advantage. Since the end of the 1970s, Ricardian Trade Theory has received little attention in the empirical literature, primarily due to the lack of a clear link between the underpinning theoretical foundations and empirical examination of the theory. The most widely used methodology for empirically examining Ricardian Trade Theory, the 'third-country method' developed by MacDougall (1951), was widely discredited as a valid test of the underlying theory (see for example Bhagwati (1964), Sailors and Bronson (1970) and Deardorff (1984)), calling into question the results of all of the earlier empirical examination of Ricardian Trade Theory, as well as those of Golub and Hsieh (2000). The lack of a clear link between theoretical foundations and the empirical examination was addressed by Costinot *et al.* (2012), who developed an innovative theoretical framework which allows them to conduct theoretically underpinned empirical tests of Ricardian Trade Theory. They found clear support for Ricardian Trade Theory across a wide range of robustness checks, for manufacturing industries across 21 countries in 1997.

The fixed effects methodology used by Costinot *et al.* (2012) allows an exploration whether Ricardian Trade Theory holds in international trade, through an examination of the significance of the elasticity of exports to observed productivity, θ, which they found to be both positive and significant across a wide range of specifications, as Ricardian Trade Theory would predict. However, their methodology does not allow them to draw any conclusions on the extent to which the pattern of relative bilateral trade can be explained by differences in relative productivities i.e. Ricardian Comparative Advantage. The fixed effects terms in their specification capture factors such as barriers to trade, preferences and wage differentials, meaning that the specific impact of relative productivities cannot be isolated. To isolate solely the impact of relative productivity differences on relative bilateral exports it is necessary to move away from a fixed effects methodology and towards a direct comparison of relative bilateral exports to relative productivities, which is the methodology adopted in this chapter. This methodology is considerably more computationally intensive which may explain why, to the best of my knowledge, it has not been adopted in the literature up to this point. Adopting this methodology allows the identification of whether Ricardian Trade Theory holds in international trade, again through an examination of the significance of the elasticity of relative bilateral exports to relative productivities, θ, but also allows the first examination of the extent to which relative productivities differences can explain relative bilateral international trade flows and, therefore, the extent to which these relative bilateral trade flows are driven by Ricardian Comparative Advantage, in a manner consistent with robust theoretical foundations.

In addition to not allowing a theoretically consistent examination of the extent to which trade flows are consistent with the predictions of Ricardian Trade Theory, the earlier empirical examinations of Ricardian Trade Theory, as well as Costinot *et al.* (2012), focus solely on the patterns of production and trade in goods industries, with no analysis of whether the pattern of trade in services is also consistent with the predictions of Ricardian Trade Theory. Given that services trade makes up an increasing proportion of international trade (from 24.6% in 2000 to 29.7% in 2015), it is of vital importance to determine whether Ricardian Trade Theory retains empirical relevance in 21st century international trade.

This chapter seeks to address the following two questions: first, to what extent can the pattern of relative bilateral international trade flows be explained by relative productivities differences, and therefore be said to be driven by Ricardian Comparative Advantage; and second, to what degree does the extent to which Ricardian Comparative Advantage drives the pattern of international trade vary across industries and countries.

This chapter is related to the wide body of empirical literature that sought to determine the validity of Ricardian Trade Theory (see for example MacDougall (1951), Stern (1962), Balassa (1963), Kreinin (1969) and recently Golub and Hsieh (2000) and Costinot *et al.* (2012)). This chapter contributes to this literature in two ways: firstly, by examining whether Ricardian Trade Theory retains empirical validity when examining both goods and services industries simultaneously, and to what extent the elasticity of trade to productivity varies across different industries; and second, by determining to what extent the pattern of bilateral trade flows can be explained by Ricardian Trade Theory, and again, how this extent varies across different industries. This chapter is also related to a wider literature that examines specialisation according to Ricardian Comparative Advantage more generally (see for example Costinot and Donaldson (2012), Jaimovich and Merella (2015) and Costinot *et al.* (2016)), as well as to the wider literature that explores the sources of comparative advantage (see for example Harrigan (1997), Romalis (2004), Nuun (2007), Manova (2008) and Sampson (n.d.)).

The rest of the chapter is organised as follows: Section 5.2 briefly outlines the theoretical framework, developed in Costinot *et al.* (2012), as well as the 'correct' method for empirically testing Ricardian Trade Theory in their framework.

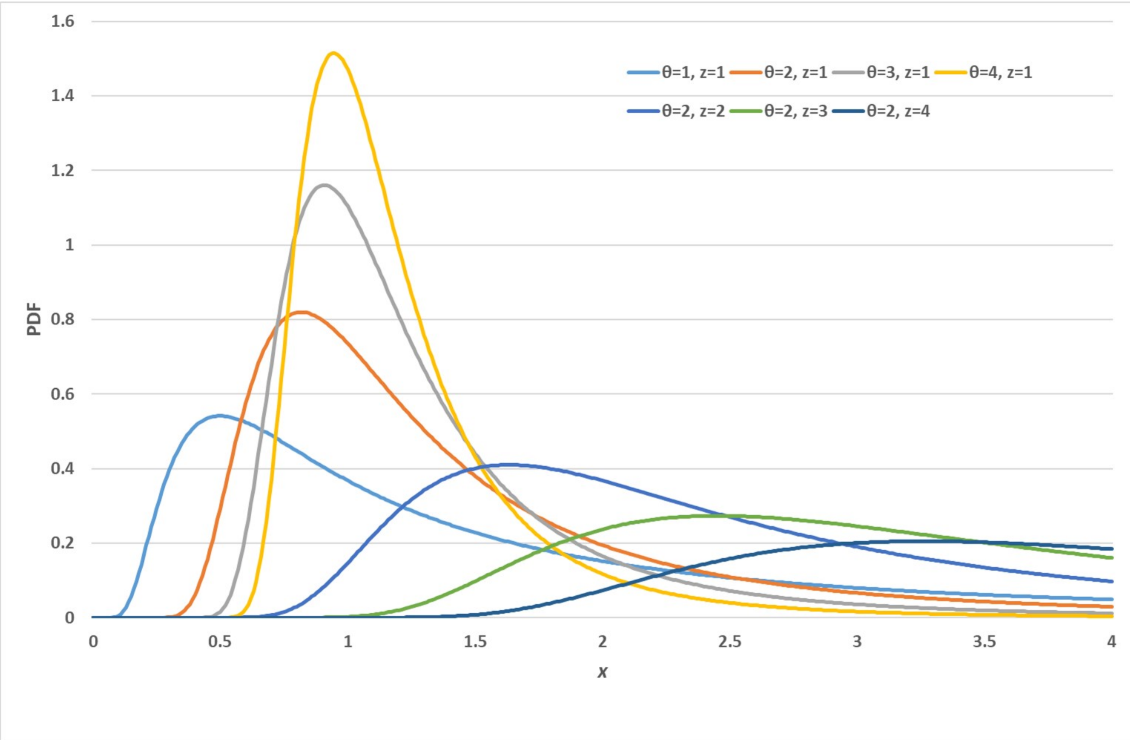
Section 5.3 presents the results of the empirical testing, divided between the baseline regression in section 5.3.2 and the alternative industry and country samples in section 5.3.3. Finally, section 5.4 concludes.

5.2 Theoretical Framework

This section briefly outlines the theoretical framework, developed by Costinot *et al.* (2012), and outlines the testable predictions of this framework. The world economy in this framework consists of $i = 1, ..., I$ countries, each with a single factor of production, labour which is assumed to be perfectly mobile between industries within each country, but immobile between countries, to allow for differentials in the wage rate. The total labour force in each country, i, is denoted by L_i, which is paid at the wage rate w_i. In each country there are $k = 1, ..., K$ industries, later divided between both goods and services industries, which display constant returns to scale in their production functions. For the purposes of the theoretical framework, all nominal variables are assumed to be denominated in a common currency, in the later empirical analysis, all nominal variables are pre-converted into a common currency (US Dollar), on a year by year basis.

In each industry in each country there will be an infinite number of different varieties, all indexed by $\omega \in \Omega \equiv \{1, ..., +\infty\}$. The number of units of output that will be produced with one unit of labour for variety ω of good k in country i, i.e. the variety specific productivity, is denoted by $z_i^k(\omega)$. As in Eaton and Kortum (2002) and Costinot *et al.* (2012), I assume that these productivities are drawn from a Frechet distribution F_i^k, such that $F_i^k(z) = \exp[-(z/z_i^k)^{-\theta}]\ \forall\ z \geq 0$, where $z_i^k > 0$, $\theta > 1$, such as to ensure that any differences in technology between any two countries will depend only on two parameters, θ and z_i^k. θ is the degree of intra-industry heterogeneity, which allows for idiosyncratic differences in technology across different varieties. Note that it is assumed that θ is identical across both different industries in the same country, but also across different countries as well. Assuming that θ is common across industries, implicitly rules out wage differentials interacting with differences in the degree of intra-industry heterogeneity across sectors to drive trade flows, allowing the model to retain the clear relationship between productivity, comparative advantage and bilateral trade flows key to Ricardian Trade Theory. In the results of this chapter θ will be the key parameter of interest, giving a measure of the elasticity of relative bilateral trade flows to changes in relative productivities. Figure 5.1, illustrates that as the value of θ increases, the productivity distribution becomes more concentrated, and that as the value of z_i^k increases, the productivity distribution becomes more dispersed.

Figure 5.1: Frechet Distribution Illustration



The other parameter that drives difference in technology, z_i^k, represents the fundamental productivity level of industry k in country i. This fundamental productivity captures all those factors that make an industry better suited to, and thus more productive in one country than another, such as climate, infrastructure, geographical conditions, both political and economic institutions and the education and health levels of the country's workforce. Within each industry k, it is solely cross country variation in z_i^k that drives cross country variations in relative labour productivity and thus the comparative advantage at the heart of Ricardian Trade Theory, given that θ is common across all countries and industries. The assumption that the productivity of each variety is drawn from a Frechet distribution formally implies the following: $z_i^k/z_{i'}^k = E[z_i^k(\omega)]/E[z_{i'}^k(\omega)]\ \forall i,\ i'$ and k. Finally, note that fundamental productivity z_i^k, will not be equal to measured productivity. In autarky the two would be equivalent, however, once countries open up to international trade some less productive varieties will be driven out of business. Thus, measured productivity, after countries have opened up to trade will be higher than the fundamental productivity that drives Ricardian Comparative Advantage. The extent to which measured productivity is higher than fundamental productivity will depend upon the degree of a country's openness. The greater the degree of openness, the greater the extent to which the less productive varieties are driven out of the market, and therefore the greater the wedge between fundamental and measured productivities.

In the Costinot *et al.* (2012) model, trade costs are of the standard 'iceberg' form, where $\tau > 1$ units of output must be shipped in order for 1 unit of output to be sold in the destination country, the remaining $\tau - 1$ units are assumed to melt away. τ_{ij}^k denotes the iceberg cost for exports in industry k from country i to country j. Note that, for simplicity, when the goods melt away they are not redistributed in any way as income through for example tariffs on imported goods. These iceberg costs incorporate not only formal barriers to trade such as tariffs or quotas, but also informal and other barriers to trade, such as transportation costs, product standards, cultural differences, geographical barriers, infrastructure barriers and language costs. All of these factors have been shown to be quantitatively important factors in determining the level of trade for both goods, see for example Disdier and Head (2008) and services, see for example Head *et al.* (2009). Given the presence of informal barriers to trade it is possible for the goods of two industries that both face no formal barriers to trade, for example through the provisions of a single market or free trade area, to have different values for the iceberg costs τ as a result of different impacts of informal barriers to trade. These informal barriers also mean that even in the presence of a single market or FTA it is not necessarily the case that $\tau_{ij}^k = \tau_{ji}^k$. To rule out cross country arbitrage opportunities, it is assumed assume that $\tau_{ij}^k \leq \tau_{il}^k \tau_{lj}^k \ \forall i,\ j$ and l.

As in Costinot *et al.* (2012), markets in the model are assumed to be perfectly competitive, which, taken with the assumption of constant returns to scale implies $p_j^k(\omega) = \min_{1 \leq i \leq I} [\tau_{ij}^k w_i / z_i^k(\omega)]$, where $\tau_{ii}^k = 1$, i.e. there are no iceberg costs if countries consume their own output. Within each industry k, for each variety ω, consumers are assumed to search between all the different countries to find the best price available. In each country, consumers have a nested utility function, as in Melitz (2003), Helpman and Krugman (1985) and similar, where the outer tier is of Cobb-Douglas form, while the inner tier is of Constant Elasticity of Substitution (CES) form. Note that the outer Cobb Douglas utility function could be replaced with any other utility function and the same testable cross sectional predictions will be derived. Therefore, along with the previous assumptions, the functional form of utility implies the following expression for total nominal expenditure on variety ω in industry k in country j: $x_j^k(\omega) = [p_j^k(\omega)/p_j^k]^{1-\sigma_j^k} \alpha_j^k w_j L_j$ where $p_j^k \equiv \left[\sum_{\omega \in \Omega} p_j^k(\omega)^{1-\sigma_j^k}\right]^{1/(1-\sigma_j^k)}$, $0 \leq \alpha_j^k \leq 1$ is the expenditure share on varieties in industry k in country j and $\sigma_j^k < 1 + \theta$ is the elasticity of substitution between varieties within the same industry. The assumption that $\sigma_j^k < 1 + \theta$ ensures that the CES price index p_j^k will be well defined in each country. Note that demand can vary both across industries in the same country, and across countries, through variation in both α_j^k and σ_j^k.

Using all of the above assumptions, it is possible[1] to derive an expression for the value of total bilateral exports from country i to country j in industry k, x_{ij}^k:

$$x_{ij}^k = \frac{(w_i \tau_{ij}^k / z_i^k)^{-\theta}}{\sum_{i'=1}^{I} (w_{i'} \tau_{i'j}^k / z_{i'}^k)^{-\theta}} \alpha_j^k w_j L_j.$$

[1]See Lemma 1 of Costinot *et al.* (2012)

Using this expression for total bilateral exports, allows me to use a difference-in-difference approach to derive an expression for relative bilateral exports, as a function of relative fundamental productivity levels and relative trade costs. Using the first difference $x_{ij}^{k}/x_{ij}^{k'}$, controls for cross country differences in wages, w_j, and labour forces, L_j, and therefore cross country differences in incomes, w_jL_j, across different import countries. Taking the second difference $(x_{ij}^{k}/x_{ij}^{k'})/(x_{i'j}^{k}/x_{i'j}^{k'})$ controls for differences in the shares of expenditure, α_j^k, across different industries within the different importing countries. Using this difference-in-difference approach, and then taking logs, gives the following relationship between relative bilateral exports, relative fundamental productivity levels, and relative trade costs:

$$ln\left(\frac{x_{ij}^{k}x_{i'j}^{k'}}{x_{ij}^{k'}x_{i'j}^{k}}\right) = \theta ln\left(\frac{z_i^k z_{i'}^{k'}}{z_i^{k'} z_{i'}^{k}}\right) - \theta ln\left(\frac{\tau_{ij}^{k}\tau_{i'j}^{k'}}{\tau_{ij}^{k'}\tau_{i'j}^{k}}\right). \tag{5.2.1}$$

Note that, as in Costinot *et al.* (2012), this equation does not examine the impact of differences in measured productivity, but solely the impact of differences in fundamental productivity levels. Remember that measured productivity is conditional on the particular variety of good being produced, whereas fundamental productivity is the theoretical productivity before production begins. To derive an expression that relates bilateral exports with measured productivity, to enable empirical testing of Ricardian Trade Theory, it is first necessary to define the relationship between fundamental and observed productivity levels. Using the assumption above that the productivity of each variety is drawn from a Frechet distribution, it can be shown that $z_i^k/z_{i'}^k = \left(\tilde{z}_i^k/\tilde{z}_{i'}^k\right) \times \left(\pi_{ii}^k/\pi_{i'i'}^k\right)^{1/\theta}$, where $\pi_{ii}^k = x_{ii}^k/\sum_{i'=1}^{I} x_{i'i}^k$ is the inverse of the degree of a country's openness, giving the proportion of a country's total consumption of the varieties from one industry k that is produced domestically, i.e. x_{ii}^k, and where $\tilde{z}_i^k$ is observed productivity in industry k in country i. This relationship is the formal form of the relationship highlighted earlier: as openness increases (π_{ii}^k decreases), the wedge between fundamental productivity z and observed or measured productivity $\tilde{z}$ increases as the less productive varieties are driven from the market. The term $\left(\pi_{ii}^k/\pi_{i'i'}^k\right)^{1/\theta}$ exactly corrects for this trade driven internal selection. Using our equation for the relationship between fundamental and observed productivity it is now possible to derive a relationship between relative exports and observed productivity:

$$ln\left(\frac{\tilde{x}_{ij}^{k}\tilde{x}_{i'j}^{k'}}{\tilde{x}_{ij}^{k'}\tilde{x}_{i'j}^{k}}\right) = \theta ln\left(\frac{\tilde{z}_{i}^{k}\tilde{z}_{i'}^{k'}}{\tilde{z}_{i}^{k'}\tilde{z}_{i'}^{k}}\right) - \theta ln\left(\frac{\tau_{ij}^{k}\tau_{i'j}^{k'}}{\tau_{ij}^{k'}\tau_{i'j}^{k}}\right), \tag{5.2.2}$$

where $\tilde{x}_{ij}^{k} = x_{ij}^{k}/\pi_{ii}^{k}$ are bilateral exports, adjusted for the degree of openness of the exporting country, henceforth 'corrected' exports. Equation (5.2.2) gives the testable predictions of the model, and allows the testing of Ricardian Trade Theory, through the sign and significance of θ in the regressions below. It is important to note however, assuming the model above is correctly specified, that relative productivities alone do not drive the pattern of relative bilateral exports, and that relative trade costs are likely to also play an important role, if there is significant variation in formal and informal barriers to trade across countries and industries. In the regressions below, given a lack of available data on barriers to trade at an importer-exporter-industry level, the trade cost term $ln\left(\frac{\tau_{ij}^{k}\tau_{i'j}^{k'}}{\tau_{ij}^{k'}\tau_{i'j}^{k}}\right)$ will be incorporated into the regression error, and thus the specification will only test the impact of relative productivity differences on relative bilateral exports, rather than testing the validity of the relationship predicted by equation (5.2.2) as a whole. As mentioned in Costinot *et al.* (2012), the approach that is used in their paper and which I adopt in my analysis, differs from the previous empirical testing of Ricardian Trade Theory in three key respects: first, the theory dictates that the dependent variable should be the log second differences of bilateral exports, corrected for the degree of openness in the exporting country. Second, the theory clarifies that general equilibrium interaction effects should not introduce significant bias into the analysis, as long as both productivity and bilateral exports are in log difference-in-difference form, and third, that the theoretical model allows the economic origins of both the error terms, and of the predictive power of Ricardian Trade Theory to be understood. If the empirical methodology derived from equation (5.2.2), has low predictive power, shown through low R^2 values, then it is likely that either there is significant variation in bilateral barriers to trade, both between industries within the same country, but also between both the same and different industries between countries, or the model is miss-specified in some way.

5.3 Results

This section investigates, first, the extent to which observed cross country differences in relative productivity can explain the cross country variation in relative bilateral trade flows, i.e. the extent to which Ricardian Comparative Advantage drives the patterns of international trade. Second, this section explores the variation in the extent to which Ricardian Comparative Advantage drives international trade across different industry samples as well as the variation in the extent to which Ricardian Comparative Advantage drives international trade across different country samples, to explore the impact of cross country variations in barriers to trade and country size.

5.3.1 Data

The tests conducted in this chapter require three different sets of data: for the baseline regression, data on labour productivity and bilateral trade flows are required, and for the instrumental variable regressions, data on Research and Development (R&D) spending at an industry level is required. Next, the sources of these data series are outlined.

Productivity

Data on productivity is obtained from the World Input Output Database (WIOD) 2016 Release Socio-Economic Accounts, see Timmer *et al.* (2015). The database reports gross output, value added, and number of persons engaged at an industry level for 43 countries and 56 industries for the years 2000-2015 inclusive. The countries include all 28 EU member countries, as well as 15 other countries, detailed in table C1 in the appendix. Ideally, as Costinot *et al.* (2012) explain, the inverse of producer price indexes would be employed as the empirical counterpart to $\tilde{z}_i^k$, however, producer price indexes are not available from the WIOD. Therefore, to ensure comparability with the older existing literature (see MacDougall (1951), Stern

(1962), Balassa (1963) and Golub and Hsieh (2000)) and the alternative measures of productivity table in Costinot *et al.* (2012), I use output per person engaged as the empirical counterpart to $\tilde{z}_i^k$. As a robustness check, I will later use value added per person engaged as the empirical counterpart to $\tilde{z}_i^k$, to correct for the higher levels of intermediate inputs used in the different industries. Costinot *et al.* (2012) show that, as a result of mis-measurement error in productivity, the coefficient of θ in regressions of output per engaged person are likely to be lower than the accurate figure, however, the ability of the model to explain cross-country patterns of bilateral trade, proxied by the regression's R^2, increases. Therefore, all results should be interpreted in this context. As a further robustness check on my results I also use Research and Development expenditure at a country-industry level to estimate an instrumental variable for each of the two measures of productivity above. Data on Research and Development at the country-industry level was obtained from the OECD '*Business enterprise R-D expenditure by industry (ISIC 4)*' database.

Bilateral Trade Flows

The values for the bilateral trade flows, x_{ij}^k, and the openness of each exporter-industry, π_{ii}^k, are obtained from the World Input-Output Tables 2016 Release, see Timmer *et al.* (2015). The tables contain data on input-output linkages at an industry level for the same 56 industries and 43 countries as the Socio-Economic accounts, plus a 'Rest of the World' aggregator for all other countries, for the years 2000-2015. The measure of x_{ij}^k is the value of bilateral exports from each of the 43 countries to all the other 42 countries, i.e. the domestic consumption of domestic production is excluded, $i \neq j$. The domestic consumption of domestic production is is excluded so that the analysis can focus solely on the pattern of international trade without any possible 'Home Bias' effects on the econometric estimates. The econometric results should therefore be interpreted as solely explaining the pattern of international trade and not the wider pattern of consumption. As outlined in section 5.2, the openness indicator, π_{ii}^k, is the proportion of domestically produced consumption in industry k in total consumption of industry k, and is calculated as follows: $\pi_{ii}^k = x_{ii}^k / \sum_{i'=1}^{I} x_{i'i}^k$.

5.3.2 Baseline Results

In the baseline specification I estimate the empirical specification first using OLS for all countries and industries, using the data described above, I then estimate the same specification using an instrumental variables (IV) approach, to correct for possible measurement errors and simultaneity bias. The empirical specification that I estimate is derived from equation (5.2.2) in section 5.2.

OLS Estimation

In the baseline specification I estimate the following model using OLS for all countries and industries, using the data described above, derived from equation (5.2.2) in section 5.2:

$$ln\left(\frac{\tilde{x}^{k}_{ij}\tilde{x}^{k'}_{i'j}}{\tilde{x}^{k'}_{ij}\tilde{x}^{k}_{i'j}}\right) = \theta\ ln\left(\frac{\tilde{z}^{k}_{i}\tilde{z}^{k'}_{i'}}{\tilde{z}^{k'}_{i}\tilde{z}^{k}_{i'}}\right) + ln\left(\frac{\epsilon^{k}_{ij}\epsilon^{k'}_{i'j}}{\epsilon^{k'}_{ij}\epsilon^{k}_{i'j}}\right),\ \forall\ i \neq i' \neq j \text{ and } k \neq k', \qquad (5.3.3)$$

where $ln\tilde{x}^{k}_{ij} = lnx^{k}_{ij} - ln\pi^{k}_{ii}$ is 'corrected' exports in industry k from country i to country j, where exports have been adjusted for the degree of exporting country industry openness. $ln\tilde{z}^{k}_{i}$ is the observed productivity, which differs from fundamental productivity because of differences in exporting country level openness π^{k}_{ii}. The error terms ϵ^{k}_{ij} incorporate both industry level variable trade costs, including both formal and informal barriers to trade, as well as potential measurement error in both the bilateral trade flows and observed productivity. This specification captures the extent to which relative bilateral trade flows are driven by relative productivity differences, and therefore the extent to which these relative bilateral trade flows are driven by Ricardian Comparative Advantage. If a country has a comparative advantage in one industry, i.e. they have a lower opportunity cost of production in that industry, $\frac{\tilde{z}^{k}_{i}}{\tilde{z}^{k'}_{i}} > \frac{\tilde{z}^{k}_{i'}}{\tilde{z}^{k'}_{i'}}$then the first country should export relatively more to a third country in that industry than the second country does in the same industry to the same third country, $\frac{\tilde{x}^{k}_{ij}}{\tilde{x}^{k'}_{ij}} > \frac{\tilde{x}^{k}_{i'j}}{\tilde{x}^{k'}_{i'j}}$. If the coefficient on θ is positive and significant when the regression is estimated, then it can be said that Ricardian Comparative Advantage drives the relative bilateral flows of international trade, and an examination of the R^2 will give the extent to which this is the case.

In Costinot *et al.* (2012), instead of the full equation above, the authors estimate the following econometrically equivalent reduced form equation with exporter importer fixed effects and importer industry fixed effects:

$$ln\tilde{x}_{ij}^{k} = \delta_{ij} + \delta_{j}^{k} + \theta\tilde{z}_{i}^{k} + \epsilon_{ij}^{k}, \tag{5.3.4}$$

where δ_{ij} and δ_{j}^{k} are, respectively exporter importer fixed effects and importer industry fixed effects. Although the reduced form equation (5.3.4) is econometrically equivalent to the full specification (5.3.3), in so far as the estimates of θ will be econometrically equivalent, there is a significant disadvantage of adopting the reduced form methodology. Specifically, by adopting this methodology there is no way of isolating the extent to which relative bilateral flows of international trade are driven by differences in relative productivities i.e. Ricardian Comparative Advantage, through an examination of the R^2 of the regression results, as the R^2 in the reduced form specification will also capture the ability of the fixed effects to predict the pattern of international trade. Therefore, to estimate how much of the relative bilateral flows of international trade are driven by differences in relative productivities it is necessary to move away from the reduced form specification (5.3.4) used in Costinot *et al.* (2012) and estimate the full specification (5.3.3)[2]. In Costinot *et al.* (2012) it was not necessary to estimate the full specification, as the focus of their analysis was on the estimation of the value and significance of θ, in order to assess whether Ricardian Trade Theory holds, and the reduced form specification is significantly less computationally intensive. However, for the purpose of my analysis the full specification is necessary, and therefore that is the specification that is estimated for the results below.

[2]While it may be possible to estimate the reduced form specification (5.3.4) with and without the productivity term and compare the R^2 values to estimate the specific impact of productivity, this would result in an underestimation of the impact of relative productivity on relative exports, due to the correlation between the productivity and the fixed effects terms. Some countries are naturally more productive in all industries, which would be captured in the fixed effects term, but is a key component of the productivity variable.

What a reduced form specification can, however, show is the validity of the model outlined in section 5.2. Given the low R^2 values estimated above for the full specification, it could be argued that the theoretical model is invalid, however, the R^2 values for the reduced form specification is high, even when such a specification has not accounted for importer-exporter-industry specific variations in barriers to trade. The high R^2 values for the reduced form specification suggest that the wider model is valid, and retains explanatory power, even if relative productivities do not account for a significant portion of the model's explanatory power.

It is important to note that, as Costinot *et al.* (2012) highlight, specifications (5.3.3) and (5.3.4) will only be fully econometrically equivalent for balanced panels. Given the missing observations in the data used for the analysis in this chapter, the reduced form estimation will only provide an average of the full specifications, across the different possible reference countries and industries. These missing observations also mean that, in order to correctly estimate both the value of θ, and the explanatory power of the overall specification, it is necessary to estimate equation (5.3.3) not only across all combinations of importer, exporter and industry, but also across all possible combinations of reference country and industry as well for every year. If the panel was balanced, with no missing observations, then the choice of reference country and industry would be irrelevant, however, given the missing observations, all combinations of importer, exporter, industry, reference country and reference industry for each year must be estimated.

Table 5.1: Baseline Regression Results

Dependent Variable	(1) log(relative 'corrected' exports)	(2) log(relative exports)	(3) log(relative 'corrected' exports)	(4) log(relative exports)
Estimation method	OLS	OLS	IV	IV
log(relative output per worker)	0.505***	0.732***	2.374***	6.034***
	(0.0001)	(0.0001)	(0.00252)	(0.00187)
Number of Observations	2,468,171,696	2,468,171,696	157,571,000	157,571,000
R^2	0.0101	0.0258	0.0056	0.0621

***, ** and * represent variables that are significant at 1%, 5% and 10% significance levels respectively.

Column 1 in Table 5.1 shows the results of the baseline OLS regression of equation (5.3.3). The table clearly shows that the estimate of θ (the parameter that estimates the impact of relative productivity on relative bilateral exports) is both positive and statistically significant at a 1% significance level, consistent with the findings of Costinot *et al.* (2012). The main difference between the estimates of θ in this chapter and previous work, such as Eaton and Kortum (2002), Simonovska and Waugh (n.d.) and Costinot *et al.* (2012), is that in this chapter, the parameter θ is estimated for trade in both goods and services. The results clearly show that, even with the expanded industry sample size, Ricardian Comparative Advantage does successfully predict the pattern of bilateral exports. However, the estimates for θ are lower than in Costinot *et al.* (2012), 0.504 compared to 1.123, driven by the larger industry and country sample in my analysis[3]. Column 2 in Table 5.1 shows the results of the same OLS regression, but where the dependent variable uses unadjusted exports, i.e. exports have not been corrected to adjust for the degree of openness in the exporting country. Consistent with the results of Costinot *et al.* (2012) my results show that not adjusting for exporting country openness would lead to an overestimation of the impact of changes in productivity on bilateral exports: 0.732 compared to 0.504 for 'corrected' exports. However, the estimated value for θ is again positive and statistically significant as would be predicted by Ricardian Trade Theory.

An examination of the R^2 values for the regressions reveals that although relative productivities do explain relative bilateral flows of international trade, the extent to which bilateral flows of international trade can be explained by relative productivities, i.e. Ricardian Comparative Advantage is low. Column 1 of Table 5.1 shows that relative productivities are only able to explain 1% of the relative bilateral flows of international trade in goods and services. Similarly to the estimates of θ, if exports are not adjusted to correct for the exporting country openness, the

[3]If we estimate equation (5.3.3 using only the industries and countries analysed in Costinot *et al.* (2012), then the value of θ increases to 0.853. The remaining difference can be explained by the use of output per worker data instead of inverse of producer price indexed, which, as Costinot *et al.* (2012) show, reduces the estimated value for θ

R^2 may be overestimated. Column 2 shows that, for unadjusted exports relative productivities can explain 2.6% of relative bilateral trade flows. However, even in this case, the vast majority of the relative bilateral flows of international trade cannot be explained by relative productivities, i.e, cannot be explained by Ricardian Comparative Advantage. It is important to note that these R^2 will not give a full explanation of the extent to which the model outlined in section 5.2 is able to predict the flows of international trade, due to the difference-in-difference approach, and the fact that the relative trade costs term, $ln\left(\frac{\tau_{ij}^{k}\tau_{i'j}^{k'}}{\tau_{ij}^{k'}\tau_{i'j}^{k}}\right)$, is incorporated into the error term.

Instrumental Variables Estimation

The large sample size for the OLS estimates above ensures the econometric consistency of the estimates, however, as Costinot *et al.* (2012) explain, there are two reasons why the OLS estimates above may be econometrically biased and therefore not give an accurate measure of the impact of Ricardian Comparative Advantage: first, measurement errors in productivity data may lead to attenuation bias, and second, endogeneity between exports and productivity, where higher exports lead to higher productivity, causing simultaneity bias. To circumvent these issues, as in Costinot *et al.* (2012) I adopt an instrumental variables (IV) approach. Adopting this approach involves estimating the values of the observed independent variable with the values of another independent variable that is correlated with the first variable, but uncorrelated with the error terms. In this chapter I instrument observed (log) productivity levels ($\tilde{z}$) with the (log) levels of research and development (R&D) at an industry level in each country. Using R&D activity to model technological change in this way follows previous work such as Eaton and Kortum (2002), Griffith *et al.* (2004) and Costinot *et al.* (2012). Implicitly, by adopting this method, I assume that relative levels of R&D spending only impact on relative bilateral exports, through the impact on relative productivities, and thus observed R&D activity is uncorrelated with the error terms including relative trade costs which are included in the error terms. However, this assumption seems reasonable, and follows the assumption made by Costinot *et al.* (2012). If there is a correlation between R&D expenditure and trade costs, then some econometric bias will remain, however, in the absence of an alternative instrument, this bias is unavoidable, and would have been present in the result of Costinot *et al.* (2012) as well. Formally, I estimate the relationship between (log) productivity and (log) levels of research and development (R&D) using OLS, and then use the fitted values of productivity that I obtain as the independent variables in the estimation of equation (5.3.3).

Estimating equation (5.3.3) using an IV methodology shows that there is evidence of significant attenuation bias in the estimates of θ. Columns 3 and 4 in Table 5.1 show the results for estimating equation (5.3.3) using IV, where the dependent variables are 'corrected' exports and unadjusted exports respectively. Consistent with the findings of Costinot *et al.* (2012) the estimated coefficient for θ, i.e. the estimated impact of differences in Ricardian Comparative Advantage, increases significantly when using an IV methodology when compared to the baseline OLS specification. Examining the R^2 for the IV specifications shows that, for the 'corrected' exports estimation there is a decrease in the extent to which the relative bilateral flows of international trade can be explained by relative productivity differences, from 1% to 0.55%. For unadjusted exports this extent increases from 2.6% to 6.2%. Finally, similarly to the results of the OLS specification, not adjusting for openness in the exporting country may lead to an overestimation of the impact of relative productivity differences on the relative bilateral flows of international trade.

Comparing the values of θ obtained using the IV methodology and output per worker as the empirical counterpart of $\tilde{z}$ to the results of the alternative productivity measures in Costinot *et al.* (2012) shows that the expansion of the sample to include services industries lowers the estimated value of θ, from 2.72 in Costinot *et al.* (2012) to 2.37 in my analysis. Intuitively, this is likely to be due to the other factors likely to be more important in driving bilateral services trade, such as cultural similarity and language barriers, shown to be a key driver of services trade by Head *et al.* (2009), which would reduce the ability of productivity differences to drive bilateral trade flows.

Robustness

For a robustness check, it is possible to use value added per worker as the empirical counterpart to $\tilde{z}$, rather than output per worker. Intuitively, as you move further down a supply chain, and thus the intermediate inputs into production increase, the difference between output per worker and fundamental productivity increases, whereas value added per worker adjusts for the level of intermediate inputs. As shown earlier in section 5.3.1, using output per worker allows a comparison of the results to the alternative productivity measures in Costinot *et al.* (2012), but may not be reflective of $\tilde{z}$ as industries further down the production chain i.e. services industries are included in the empirical analysis. Table 5.2 shows the results of the same analysis as in Table 5.1, but where the independent variable is log(relative value added per worker) instead of log(relative output per worker).

Table 5.2: Baseline Value Added Per Worker Regression Results

Dependent Variable	(1) log(relative 'corrected' exports)	(2) log(relative exports)	(3) log(relative 'corrected' exports)	(4) log(relative exports)
Estimation method	OLS	OLS	IV	IV
log(relative value added per worker)	0.375***	0.561***	1.911***	4.856***
	(0.0001)	(0.0001)	(0.00252)	(0.00187)
Number of Observations	2,468,171,696	2,468,171,696	157,571,000	157,571,000
R^2	0.0052	0.0141	0.0056	0.0621

***, ** and * represent variables that are significant at 1%, 5% and 10% significance levels respectively.

The results obtained using value added per worker instead of output per worker as the empirical counterpart to $\tilde{z}$ in Table 5.2 show clearly that more accurately estimating productivity significantly reduces the estimated value for θ. For all four different estimations, using OLS and IV and relative 'corrected' and unadjusted exports, the estimated value for θ, although still positive and significant, indicating evidence in favour of Ricardian Trade Theory, are all smaller than when output per worker data is used.

Referring back to equation (5.2.2) in section 5.2, it is clear that a low R^2 for both the OLS and IV specifications for equation (5.3.3) using both value added per worker and output per worker to measure productivity, implies that the vast majority of the differences in relative bilateral flows of international trade are driven not by differences in relative productivities $\left(\frac{z_i^k z_{i'}^{k'}}{z_i^{k'} z_{i'}^k}\right)$, but instead by other factors, such as possibly differences in relative barriers to trade $\left(\frac{\tau_{ij}^k \tau_{i'j}^{k'}}{\tau_{ij}^{k'} \tau_{i'j}^k}\right)$, which are incorporated into the error term. Note that, if an analysis did not estimate the full specification (5.3.3), but instead a reduced form equation with importer industry and exporter importer fixed effects, as in Costinot *et al.* (2012), then the R^2 values in the specification would not be able to isolate the extent to which relative bilateral flows of international trade are driven by Ricardian Comparative Advantage, as the fixed effects will be explaining some of the variation in trade flows.

The findings above would be consistent with a sectoral gravity equation, if for example, the decrease in trade volumes from a 1km increase in distance was different for one industry than another. In that case, the 'iceberg' cost associated with distance alone, denoted by τ_{DISTij}^k, would be different both between industries in the same country, $\tau_{DISTij}^k \neq \tau_{DISTij}^{k'}$, but would also be in different proportions the same two industries in two different countries $\tau_{DISTij}^k / \tau_{DISTij}^{k'} \neq \tau_{DISTi'j}^k / \tau_{DISTi'j}^{k'}$. The variation in the impact of barriers to trade across different industries is likely to be greater than solely the impact of distance, as for example the impact of cultural similarity could vary across industries, or the impact of language similarity. A similar argument would apply to the impact of tariffs on bilateral trade flows between two countries within a Free Trade Area (FTA), relative to bilateral trade flows between the same importer country and a country outside the FTA. As long as the tariff schedule for imports in industry k is not the same as in industry k', then there will be variation in cross country relative barriers to trade. Denote by τ_{TRij}^k the tariff barrier to imports. For the countries in the FTA $\tau_{TRij}^k = \tau_{TRij}^{k'} = 1$, but for the countries outside the FTA $\tau_{TRi'j}^k \neq \tau_{TRi'j}^{k'}$, therefore $\tau_{TRij}^k / \tau_{TRij}^{k'} \neq \tau_{TRi'j}^k / \tau_{TRi'j}^{k'}$. The specifications above show that variations in these importer-exporter-industry specific barriers to trade have the potential to explain a significant proportion of the relative bilateral flows of international trade, if the model in section 5.2 is correctly specified, given how small a proportion of these relative bilateral trade flows can be explained by relative productivities.

To examine whether the intuition above is correct, it is possible to estimate equation (5.3.3) above for only those industries which are likely to have less importer-exporter-industry specific variation. In the next section I estimate equation (5.3.3), the baseline regression specification, for different samples of industries and countries, and then conduct a meta-analysis to determine those industries and countries for which the relative productivities are better able to explain the relative bilateral flows of international trade.

5.3.3 Alternative Samples

Next, I explore how the extent to which relative bilateral flows of international trade can be explained by relative productivities varies across different samples of countries and industries, and the intuition behind this variation, including the first examination of the extent to which relative productivities can explain relative bilateral flows of international trade in services. To examine the variation in the ability of relative productivities to explain relative bilateral trade flows, I estimate equation (5.3.3) above for eight sub-samples of industries, and 5 sub-samples of countries, using both the measures of productivity (value added per worker and output per worker), as well as both 'corrected' and unadjusted exports as the dependent variable using both OLS and IV specifications. The eight industry samples are as follows: 1) industries with an export to output ratio of greater than 5%, 2) industries with an export to output ratio of greater than 10%, 3) goods industries with an export to output ratio of greater than 10%[4], 4) the industries used in Costinot *et al.* (2012), 5) manufacturing industries, 6) all services industries, 7) services industries with an export to output ratio of greater than 5% and 8) services industries with an export to output ratio of greater than 10%. The full list of which industry is in which sample is in Table C2 in the appendix. The five country samples

[4]Note that sample 3 contains all goods industries other than ISIC Codes A01, C18, D and E36.

are as follows: 1) the countries used in Costinot *et al.* (2012), 2) countries de facto in the EU Single Market, 3) countries in the EU, 4) countries not in the EU or EEA and 5) Countries whose GDP is in the world's top 20. The full list of which country is in which sample is in Table C3 in the appendix.

Meta-Analysis

In order to estimate the drivers of deviations from Ricardian Comparative Advantage and the determinants of the extent to which relative bilateral flows of international trade can be explained by relative productivities, I next conduct a meta-analysis on the results of my estimations for different industry and country samples. Although meta-analysis as a tool is more widely used to compare the results of different studies within a literature, it is also appropriate for comparing the results across my different sub-samples.

Once the regressions for each possible combination of industry sample, country sample, independent variable and dependent variable samples have been estimated I next conduct a meta-analysis on the results of these specifications, specifically to examine the determinants of both the value of θ and the extent to which relative bilateral flows of international trade can be explained by relative productivity differences. Given the two different dependent variables, and two different possible independent variables, along with the nine possible industry samples (1 full sample and 8 sub-samples) and six possible country samples (1 full sample and 5 sub-samples) I have $2 \times 2 \times 9 \times 6 = 216$ observations for each of the OLS and IV specifications. To examine the impact of each sub sample, while controlling for differences between the different independent and dependent variables, as a data fitting exercise, given the lack of a model for the data generating process, I estimate the following two OLS regressions, with fixed effects for regressions that use output per worker and 'corrected' exports, as well as fixed effects for each industry and country sub sample, using, as the dependent variables, the the regression R^2 and the coefficient of θ from the estimates of equation (5.3.3) for each combination of industry sample, country sample, independent variable and dependent variable:

$$R^2 = \alpha_0 + \alpha_1 \delta_{Indep} + \alpha_2 \delta_{Dep} + \sum_{n=1}^{8} \alpha_{n+3} \delta_{Ind\ n} + \sum_{m=1}^{5} \alpha_{m+11} \delta_{Con\ m} + \epsilon \tag{5.3.5}$$

$$\theta = \beta_0 + \beta_1 \delta_{Indep} + \beta_2 \delta_{Dep} + \sum_{n=1}^{8} \beta_{n+3} \delta_{Ind\ n} + \sum_{m=1}^{5} \beta_{m+11} \delta_{Con\ m} + \epsilon \tag{5.3.6}$$

Table 5.3 shows the results of my meta-analysis using, as the dependent variable the regression R^2 (Columns 1 & 2) and the coefficient of θ (Columns 3 & 4)from the estimates of equation (5.3.3) for each combination of industry sample, country sample, independent variable and dependent variable for both the OLS (Columns 1 & 3) and IV (Columns 2 & 4) specifications. Examining first the impact of the different industry and country samples on the extent to which international trade can be explained using Ricardian Trade Theory, in columns 1 and 2, we can observe that for both the OLS and IV specifications, focusing on only those industries with export to output ratios of greater than 5% and 10% the ability of Ricardian Comparative Advantage to explain bilateral trade flows is substantially larger. For the IV specification there are on average a 2.9% point and a 3.6% point increase in the R^2 values for industries with export to output ratios of greater than 5% and 10% relative to all industries. If deviations from Ricardian Comparative Advantage are driven by difference in relative trade costs, then these results are as we would expect. Bilateral trade flows in those industries that are more tradeable internationally will have lower variation in relative trade costs, compared to industries that are relatively less tradeable, such as construction.

If we examine the difference between the ability of Ricardian Trade Theory to explain bilateral trade flows in goods and in services we can see further evidence that relative trade barriers are driving deviations from Ricardian Comparative Advantage. Comparing the coefficient on δ_{Ind3} and δ_{Ind6}, in columns 1 and 2 we can see that in both the OLS and IV specifications the coefficient on δ_{Ind3} is positive and significant, while the coefficient on δ_{Ind6} is negative and significant. This

Table 5.3: Meta-Analysis Results

Dependent Variable	(1) OLS R^2	(2) IV R^2	(3) OLS θ
Constant	0.0318***	0.0765***	0.692***
	(0.0055)	(0.0106)	(0.0464)
δ_{Ind1} (5% Tradeable)	0.0130**	0.0289**	0.0952*
	(0.00584)	(0.0113)	(0.0493)
δ_{Ind2} (10% Tradeable)	0.0204***	0.0428***	0.146***
	(0.00584)	(0.0113)	(0.0493)
δ_{Ind3} (10% Tradeable Goods)	0.0210***	0.0438***	0.0102**
	(0.00584)	(0.0113)	(0.0493)
δ_{Ind4} (Costinot *et al.* (2012))	0.0210***	0.0358***	-0.0239
	(0.00584)	(0.0113)	(0.0493)
δ_{Ind5} (Manufacturing)	0.0195***	0.0237**	0.0400
	(0.00584)	(0.0113)	(0.0493)
δ_{Ind6} (Services)	-0.0953	-0.0329***	-0.174***
	(0.00584)	(0.0113)	(0.0493)
δ_{Ind7} (5% Tradeable Services)	0.00598	-0.0205*	-0.0169
	(0.00584)	(0.0113)	(0.0493)
δ_{Ind8} (10% Tradeable Services)	0.0163***	-0.0169	0.0666
	(0.00584)	(0.0113)	(0.0493)
δ_{Con1} (Costinot *et al.* (2012))	0.0206***	0.0212**	0.184***
	(0.00477)	(0.00919)	(0.0403)
δ_{Con2} (Single Market)	0.0216***	0.0109	0.138***
	(0.00477)	(0.00919)	(0.0403)
δ_{Con3} (EU)	0.0219***	0.00755	0.118***
	(0.00477)	(0.00919)	(0.0403)
δ_{Con4} (Non-EU)	-0.0155***	0.00424	-0.194***
	(0.00477)	(0.00919)	(0.0403)
δ_{Con5} (Top 20 by GDP)	-0.0160***	-0.00676	-0.212***
	(0.00477)	(0.00919)	(0.0403)
Dependent Variable FE	YES	YES	YES
Independent Variable FE	YES	YES	YES
Number of Observations	216	216	216
R^2	0.626	0.655	0.619

***, ** and * represent variables that are significant at 1%, 5% and 10% significance levels respectively.

means that bilateral goods trade is better explained by Ricardian Trade Theory and bilateral services trade is less well explained by Ricardian Trade Theory than for all bilateral flows of international trade. It is likely that services trade will have significantly more variation in relative trade costs, reflecting dissimilarities in regulatory standards across different industries, cultural differences, language barriers etc., which are likely to more significantly impact services industries, as in

Head *et al.* (2009), compared to goods industries. The variation in relative trade costs, increases the size of the $\left(\frac{\tau_{ij}^{k}\tau_{i'j}^{k'}}{\tau_{ij}^{k'}\tau_{i'j}^{k}}\right)$ term in equation (5.2.2), which increases the relative error term term in equation (5.3.3), driving increased deviation from Ricardian Comparative Advantage, and reducing the ability of Ricardian Trade Theory to explain the pattern of bilateral international trade.

The final piece of evidence that relative trade cost differences are driving deviations from Ricardian Comparative Advantage is obtained by examining bilateral trade flows for countries inside the EU compared to countries outside the EU. Comparing the coefficient on Country fixed effects two, three and four in column 1 shows that for the OLS specification[5] the coefficient on δ_{Con2} and δ_{Con3} are positive, while the coefficient on δ_{Con4} is negative and significant. This means that bilateral trade for countries inside the EU/EEA (δ_{Con2}) or inside the EU (δ_{Con3}) is better explained by Ricardian Trade Theory and bilateral trade for countries outside the EU is less well explained by Ricardian Trade Theory than trade between all countries. Differences in relative trade costs are likely to be much smaller inside a FTA, such as the EU/EEA, which allows more of the variation in bilateral trade flows to be driven by productivity differences.

Next, the results of the meta-analysis highlight why the results for my baseline OLS regression gave a lower estimated value for θ than the value estimated by Costinot *et al.* (2012). Column 3 of Table 5.3, shows that for the particular country sample used in their paper, compared to a larger country sample, the estimated value of θ is higher. The results also show that even if Costinot *et al.* (2012) had estimated a direct comparison of relative bilateral exports to relative productivity, it is likely that they would not have been able to give an accurate estimate of the extent to

[5]Column 2 shows that for the IV specification there is little variation in the ability of Ricardian Trade Theory to explain bilateral trade flows across different country samples, driven mainly by the significant number of missing observations in R and D data for less tradeable/ services industries in Non-EU countries. Therefore it appears that Ricardian Trade Theory can explain bilateral trade flows in Non-EU countries solely because of the industries for which data is available for those countries are those industries whose trade is likely to be driven more by Ricardian Comparative Advantage and less by relative trade costs.

which relative productivities can explain the overall patterns of relative bilateral trade, as both the particular industry sample and the particular country sample give higher values for R^2 than for the whole industry and country samples.

5.4 Conclusion

In this chapter I used the innovative theoretical framework developed by Costinot *et al.* (2012) to offer the first exploration of the extent to which relative bilateral flows of international trade can be explained by differences in relative productivity, and thus the extent to which these flows are driven by Ricardian Comparative Advantage. Unlike the fixed effect methodology used in their paper, I use a more computationally intensive method, which enables the impact of Ricardian Comparative Advantage to be isolated separately from exporter-importer or importer-industry specific barriers to trade. I also extend the previous examinations of trade in goods to provide the first examination of whether Ricardian Comparative Advantage drives relative bilateral international trade in services. Finally, using a meta-analysis I examine the drivers of deviations from the patterns of trade expected if trade was driven solely by Ricardian Comparative Advantage. Two main results stand out from my examination:

First, although Ricardian Trade Theory holds for relative bilateral international trade flows in both goods, consistent with the findings of Costinot *et al.* (2012), and services, shown by the positive and significant coefficient on the elasticity of relative exports to relative productivity, θ, the extent to which these relative bilateral trade flows are driven by Ricardian Comparative Advantage is low. In the baseline specifications, a maximum of 1% of relative bilateral trade flows can be explained by relative productivity differences. This result is robust to different specifications and industry and country samples, and therefore other factors such as barriers to trade, wage differentials and preferences are needed to explain the vast majority of relative bilateral trade flows.

Second, the proportion of relative bilateral international trade flows that can be explained by differences in relative productivities is larger for goods industries than for services industries, driven by larger differences in importer-exporter-industry specific barriers to trade in services, such as cultural or language differences that have a significantly more heterogeneous impact on different services sectors than different goods sectors, consistent with the findings of Head *et al.* (2009). Thus, as services trade becomes an increasingly large portion of international trade, barring any changes in the relative heterogeneity of importer-exporter-industry specific barriers to trade in services we would expect the extent to which relative bilateral flows of international trade are driven by Ricardian Comparative Advantage to decline over time. Thus more focus needs to be placed on the identification of the impact of importer-exporter-industry specific barriers to trade, to allow accurate ongoing predictions of the patterns of international trade.

Chapter 6

Conclusions

This aim of this thesis is to contribute to our understanding of the links between international trade and productivity, by further developing our understanding of both the impact of changes in international trade on productivity, as well as the impact of changes in productivity on international trade. To further this understanding, I have sought to answer three significant research questions:

1. To what extent do changes in the origin of a country's imports matter for the impact of international trade on productivity, once changes in the overall volume of trade are accounted for?

2. How does the endogenous response of less productive non-trading domestic firms affect the response of productivity to changes in barriers to trade and other macroeconomic shocks?

3. To what extent are relative bilateral flows of international trade explained by differences in relative productivity levels, and thus, to what extent are these flows driven by Ricardian Comparative Advantage?

After a comprehensive literature review, presented in Chapter 2, examining the links between trade and productivity, Chapter 3 addresses the first of these questions, and shows that in addition to the significant effect of import volumes on productivity, observed in previous studies (see for example Hung *et al.* (2004), Amiti and Konings (2007) and Bloom *et al.* (2016)), if a shift in the origin of a country's imports is exogenously driven, it can cause changes in productivity. This chapter shows that such an exogenous shift in the origin of UK services imports away from the EU and towards Non-EU countries around the time of the Great Recession caused around a 1.7% decrease in UK productivity. However, the decrease in the proportion of UK goods imports originating in the EU at the same time was endogenously driven, and thus its effect on UK productivity cannot be identified.

In Chapter 4 a new theoretical Dynamic Stochastic General Equilibrium (DSGE) model, building on Ghironi and Melitz (2005), was developed to incorporate an endogenous response of less productive non-trading domestic firms. This model is then used to show that, unlike in previous theoretical models such as Ghironi and Melitz (2005) or Fattel Jaef and Lopez (2014), the endogenous response of these firms allows the model to match the observed large increases in productivity in response to barrier to import reductions seen in the empirical literature such as Bloom *et al.* (2016). This chapter also shows that the endogenous response of less productive non-trading firms introduces further endogeneity into the persistence of labour productivity, on top of the limited endogeneity in existing models such as Ghironi and Melitz (2005) or Fattel Jaef and Lopez (2014).

In Chapter 5 the innovative theoretical framework developed by Costinot *et al.* (2012) was adopted, to present the first empirical test of the extent to which Ricardian Comparative Advantage drives the relative bilateral flows of international trade. Although the previous empirical testing such as MacDougall (1951), Bhagwati (1964) and Costinot *et al.* (2012) could assess whether Ricardian Trade Theory holds, they could not determine the extent to which relative bilateral flows of international trade can be explained by differences in relative productivity levels. This chapter builds on this literature and concludes that although Ricardian Trade Theory holds across a wide range of countries and industries, consistent with the existing literature, only a very small percentage of the bilateral flows of international trade can be explained by differences in relative productivities.

Future research building on my thesis might explore the following issues:

First, to what extent are the findings that a shift in the origin of imports, if exogenously driven, can affect productivity robust to a wider sample of countries and greater disaggregation of industries? Identifying exogenous shifts in the origin of imports may prove to be difficult, hence the focus of the analysis solely on UK services imports, where the exogeneity of the shift was identifiable.

Second, how would the response of less productive non-trading firms vary in models in which the assumptions of trade balance in every period and zero unemployment were relaxed? Given the persistent trade deficits observed for many countries, and the significant interactions between the responses of unemployment and productivity to macroeconomic shocks this is an important topic for future research.

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Appendix A

Appendices to Chapter 3

A.1 Unit Root Tests

The regression equation for the ADF test is as follows:

$$\Delta X_t = \beta_0 + \beta_1 t + \beta_2 X_{t-1} + \sum_{i=1}^{n} \phi_i \Delta X_{t-1} + \epsilon_t, \tag{A.1.1}$$

where ϵ_t is the regression error, which by assumption is stationary with zero mean and constant variance. Both the ADF and Phillips-Perron tests perform a significance test on the coefficient of X_{t-1}. The Phillips-Perron test is based on the regression equation above, except that the lagged difference terms $(\sum_{i=1}^{n} \phi_i \Delta X_{t-1})$ are excluded, in order to first test the significance of the coefficient of X_{t-1} without the assumptions for the degrees of serial correlation between the lagged difference terms. To increase the robustness of our checks, the ADF test is run, with a number of lagged differences included, according to the optimal lag length given by the Schwarz Information Criteria (SIC). Given that the optimal lag length according to the SIC was 0, the two tests are identical. Both tests were first performed with a constant only, and then with a constant and trend.

Table A1: Unit Root Test Results

Variable	ADF Test		Phillips-Perron Test	
	Constant	Trend and Constant	Constant	Trend and Constant
Levels:				
PROD_TS	-2.525[0]	0.1893[0]	-2.252	0.1893
IS_S	-1.747[0]	-1.584[0]	-1.747	-1.584
IM_S	-2.265[0]	-0.6583[0]	-2.265	-0.6583
First Difference:				
ΔPROD_TS	-2.997*[0]	-4.006*[0]	-2.997*	-4.006*
ΔIS_S	-5.250**[0]	-5.215**[0]	-5.250**	-5.215**
ΔIM_S	-4.505**[0]	-6.088**[0]	-4.505**	-6.088**

Notes: The figures in brackets denote the optimal lag length, determined using the Schwarz Information Criteria. Significant at or below ** 1% and * 5% significance.

A.2 Johansen (1991) Maximum Eigenvalue and Trace Tests

The Johansen (1991) test identifies the number of cointegrating relationships using two likelihood ratio tests: the maximum eigenvalue test (λ_{max}) and trace test (λ_{trace}).

Table A2: Johansen (1991) Maximum Eigenvalue and Trace Test Results

Sector	Variables	H_0: Rank= r	$r = 0$	$r \leq 1$	$r \leq 2$
Services	PROD_TS, IS_S, IM_S	Eigenvalue	0.61245	0.38849	0.13447
		λ_{max}	22.749*	11.804	3.466
		5% Critical Values	21.132	14.265	3.841
		λ_{trace}	38.019**	15.269	3.466
		5% Critical Values	29.797	15.495	3.841

Note: Significant at or below ** 1% and * 5% significance.

A.3 Schwartz Information Criteria and Hannan-Quinn Criteria Optimal Lag Length

Table A3: Schwartz Information Criteria and Hannan-Quinn Criteria Optimal Lag Length

Variables	Lag Length	SIC	HQC
PROD_TS, IS_S, IM_S	1	-14.281*	-14.492*
	2	-13.968	-14.328
	3	-13.533	-14.051
	4	-13.004	-13.686

Note:* Denotes optimal lag length chosen by SIC/HQC.

A.4 Tradable Goods - Tests Results

Table A4: Unit Root Test Results

Variable	ADF Test		Phillips-Perron Test	
	Constant	Trend and Constant	Constant	Trend and Constant
Levels:				
PROD_TG	-2.973[0]	-0.9855[0]	-2.973	-0.9855
IS_G	-1.894[0]	-3.475[5]	-1.950	-1.985
IM_G	-1.094[0]	-2.450[0]	-1.094	-2.450
First Difference:				
ΔPROD_TG	-3.176*[0]	-4.322*[0]	-3.176*	-4.322*
ΔIS_G	-3.895**[5]	-3.759*[5]	-4.566**	-4.488**
ΔIM_G	-5.464**[0]	-5.587**[0]	-5.464**	-5.587**

Notes: The figures in brackets denote the optimal lag length, determined using the Schwarz Information Criteria. Significant at or below ** 1% and * 5% significance.

Table A5: Johansen (1991) Maximum Eigenvalue and Trace Test Results

Sector	Variables	H_0: Rank= r	$r = 0$	$r \leq 1$	$r \leq 2$
Services	PROD_TG, IS_G, IM_G	Eigenvalue	0.54683	0.314797	1.01 $\times 10^{-6}$
		λ_{max}	18.996*	9.073	2.43×10^{-5}
		5% Critical Values	17.797	11.224	4.129
		λ_{trace}	28.068**	9.073	2.43×10^{-5}
		5% Critical Values	24.276	12.321	4.129

Note: Significant at or below ** 1% and * 5% significance.

Table A6: Schwartz Information Criteria and Hannan-Quinn Criteria Optimal Lag Length

Variables	Lag Length	SIC	HQC
PROD_TG, IS_G, IM_G	1	-14.466*	-14.678*
	2	-13.881	-14.241
	3	-13.297	-13.814
	4	-13.287	-13.969

Note:* Denotes optimal lag length chosen by SIC/HQC.

Long Run Relationship Estimation:

$$\underset{}{PROD\_TG_t} = \underset{(1.792)^{**}}{4.6927} + \underset{(0.9492)^{**}}{2.4397} IS\_G_t + \underset{(0.1542)^{***}}{1.6266} IM\_G_t + \theta G_t. \tag{A.4.2}$$

Rearranging, we obtain the estimated residual equation:

$$\widehat{\theta G_t} = PROD\_TG_t - 4.6927 - 2.4397 IS\_G_t - 1.6266. IM\_G_t \tag{A.4.3}$$

Table A7: CADF and Phillips-Perron Unit Root Test Results

Variable	CADF Test	Phillips-Perron Test
$\widehat{\theta S_{t-1}}$	-2.731** [0]	-2.731**

Notes: The figures in brackets denote the optimal lag length, determined using the Schwarz Information Criteria. Significant at or below ** 1% and * 5% significance.

Estimated VECM Equations:

$$\Delta PROD\_TG_t = \mu_1+\alpha_{11}\widehat{\theta G_{t-1}}+\alpha_{21}\Delta PROD\_TG_{t-1}+\alpha_{31}\Delta IS\_G_{t-1}+\alpha_{41}\Delta IM\_G_{t-1}+\epsilon_{4t}, \quad (A.4.4)$$

$$\Delta IS\_G_t = \mu_2+\alpha_{12}\widehat{\theta G_{t-1}}+\alpha_{22}\Delta PROD\_TG_{t-1}+\alpha_{32}\Delta IS\_G_{t-1}+\alpha_{42}\Delta IM\_G_{t-1}+\epsilon_{5t}, \quad (A.4.5)$$

$$\Delta IM\_G_t = \mu_3+\alpha_{13}\widehat{\theta G_{t-1}}+\alpha_{23}\Delta PROD\_TG_{t-1}+\alpha_{33}\Delta IS\_G_{t-1}+\alpha_{43}\Delta IM\_G_{t-1}+\epsilon_{6t}. \quad (A.4.6)$$

Table A8: Goods VECM Results

Equation	Dependent Variable	$\widehat{\theta S_{t-1}}$	$\Delta PROD\_TS_{t-1}$	ΔIS_S_{t-1}	ΔIM_S_{t-1}	F_1	F_2	Constant
(A.4.4)	$\Delta PROD\_TG_t$	-0.008375	0.5305***	-0.2489	-0.6210***	0.14778	4.1248**	0.01613**
		(0.1090)	(0.1862)	(0.4739)	(0.2169)			(0.006385)
(A.4.5)	ΔIS_G_t	-0.02134	-0.05662	-0.01084	-0.01149	0.30930	0.0066525	4.963×10^{-3}
		(0.05928)	(0.1012)	(0.2577)	(0.1180)			(0.003472)
(A.4.6)	ΔIM_G_t	-0.2282**	0.1450	-0.08132	-0.2427	3.5990**	3.0404*	0.01231*
		(0.1040)	(0.1777)	(0.4522)	(0.2070)			(0.006093)

Notes: The figures in brackets are the standard errors. Significant at or below *** 1%, ** 5% and *10% significance.

Appendix B

Appendices to Chapter 4

Table B1: Equations of the Model

Equation Name	Equation
Price Indexes	$N^h_{Dt}(\tilde{\rho}^h_{Dt})^{1-\theta} + N^i_{Xht}(\tilde{\rho}^i_{Xht})^{1-\theta} + N^j_{Xht}(\tilde{\rho}^j_{Xht})^{1-\theta} = 1$ $N^i_{Dt}(\tilde{\rho}^i_{Dt})^{1-\theta} + N^h_{Xit}(\tilde{\rho}^h_{Xit})^{1-\theta} + N^j_{Xit}(\tilde{\rho}^j_{Xit})^{1-\theta} = 1$ $N^j_{Dt}(\tilde{\rho}^j_{Dt})^{1-\theta} + N^h_{Xjt}(\tilde{\rho}^h_{Xjt})^{1-\theta} + N^i_{Xjt}(\tilde{\rho}^i_{Xjt})^{1-\theta} = 1$
Domestic Price	$\tilde{\rho}^h_{Dt} = \frac{\theta}{\theta-1}\frac{w^h_t}{Z^h_t \tilde{z}^h_{Dt}}$ $\tilde{\rho}^i_{Dt} = \frac{\theta}{\theta-1}\frac{w^i_t}{Z^i_t \tilde{z}^i_{Dt}}$ $\tilde{\rho}^j_{Dt} = \frac{\theta}{\theta-1}\frac{w^j_t}{Z^j_t \tilde{z}^j_{Dt}}$
Export Price	$\tilde{\rho}^h_{Xit} = \frac{\theta}{\theta-1}\frac{\tau^h_{it}}{Q^i_t}\frac{w^h_t}{Z^h_t \tilde{z}^h_{Xit}}$ $\tilde{\rho}^h_{Xjt} = \frac{\theta}{\theta-1}\frac{\tau^h_{jt}}{Q^j_t}\frac{w^h_t}{Z^h_t \tilde{z}^h_{Xjt}}$ $\tilde{\rho}^i_{Xht} = \frac{\theta}{\theta-1}Q^i_t \tau^i_{ht}\frac{w^i_t}{Z^i_t \tilde{z}^i_{Xht}}$ $\tilde{\rho}^i_{Xjt} = \frac{\theta}{\theta-1}\frac{Q^j_t \tau^i_{jt}}{Q^i_t}\frac{w^i_t}{Z^i_t \tilde{z}^i_{Xjt}}$ $\tilde{\rho}^j_{Xht} = \frac{\theta}{\theta-1}Q^j_t \tau^j_{ht}\frac{w^j_t}{Z^j_t \tilde{z}^j_{Xht}}$ $\tilde{\rho}^j_{Xit} = \frac{\theta}{\theta-1}\frac{Q^i_t \tau^j_{it}}{Q^j_t}\frac{w^j_t}{Z^j_t \tilde{z}^j_{Xit}}$
Total Firm Profits	$\tilde{d}^h_t = \tilde{d}^h_{Dt} + \frac{N^h_{Xit}}{N^h_{Dt}}\tilde{d}^h_{Xit} + \frac{N^h_{Xjt}}{N^h_{Dt}}\tilde{d}^h_{Xjt}$ $\tilde{d}^i_t = \tilde{d}^i_{Dt} + \frac{N^i_{Xht}}{N^i_{Dt}}\tilde{d}^i_{Xht} + \frac{N^i_{Xjt}}{N^i_{Dt}}\tilde{d}^i_{Xjt}$ $\tilde{d}^j_t = \tilde{d}^j_{Dt} + \frac{N^j_{Xht}}{N^j_{Dt}}\tilde{d}^j_{Xht} + \frac{N^j_{Xit}}{N^j_{Dt}}\tilde{d}^j_{Xit}$
Domestic Profits	$\tilde{d}^h_{Dt} = \frac{C^h_t}{\theta}(\tilde{\rho}^h_{Dt})^{1-\theta} - \frac{w^h_t f^h_D}{Z^h_t}$ $\tilde{d}^i_{Dt} = \frac{C^i_t}{\theta}(\tilde{\rho}^i_{Dt})^{1-\theta} - \frac{w^i_t f^i_D}{Z^i_t}$ $\tilde{d}^j_{Dt} = \frac{C^j_t}{\theta}(\tilde{\rho}^j_{Dt})^{1-\theta} - \frac{w^j_t f^j_D}{Z^j_t}$
Export Profits h	$\tilde{d}^h_{Xit} = \frac{C^i_t Q^i_t}{\theta}(\tilde{\rho}^h_{Xit})^{1-\theta} - \frac{w^h_t f^h_{Xi}}{Z^h_t}$ $\tilde{d}^h_{Xjt} = \frac{C^j_t Q^j_t}{\theta}(\tilde{\rho}^h_{Xjt})^{1-\theta} - \frac{w^h_t f^h_{Xj}}{Z^h_t}$ $\tilde{d}^i_{Xht} = \frac{C^h_t Q^h_t}{\theta}(\tilde{\rho}^i_{Xht})^{1-\theta} - \frac{w^i_t f^i_{Xh}}{Z^i_t}$ $\tilde{d}^i_{Xjt} = \frac{C^j_t Q^j_t}{\theta}(\tilde{\rho}^i_{Xjt})^{1-\theta} - \frac{w^i_t f^i_{Xj}}{Z^i_t}$ $\tilde{d}^j_{Xht} = \frac{C^h_t Q^h_t}{\theta}(\tilde{\rho}^j_{Xht})^{1-\theta} - \frac{w^j_t f^j_{Xh}}{Z^j_t}$ $\tilde{d}^j_{Xit} = \frac{C^i_t Q^i_t}{\theta}(\tilde{\rho}^j_{Xit})^{1-\theta} - \frac{w^j_t f^j_{Xi}}{Z^j_t}$

Equation Name	Equation
Free Entry Condition	$\tilde{v}_t^h = \left(\frac{E(z^h_{Dt+1})}{z^h_{min}}\right)^k \frac{w_t^h f_E^h}{Z_t^h}$ $\tilde{v}_t^i = \left(\frac{E(z^i_{Dt+1})}{z^i_{min}}\right)^k \frac{w_t^i f_E^i}{Z_t^i}$ $\tilde{v}_t^j = \left(\frac{E(z^j_{Dt+1})}{z^j_{min}}\right)^k \frac{w_t^j f_E^j}{Z_t^h}$
New Firm Entry Condition	$N^h_{Dt} = (1-\delta)(N^h_{Dt-1} + N^h_{Et-1})$ $N^i_{Dt} = (1-\delta)(N^i_{Dt-1} + N^i_{Et-1})$ $N^j_{Dt} = (1-\delta)(N^j_{Dt-1} + N^j_{Et-1})$
Proportion of Firms That Export	$\frac{N^h_{Xit}}{N^h_{Dt}} = (\tilde{z}^h_{Dt})^k(\tilde{z}^h_{Xit})^k$ $\frac{N^h_{Xjt}}{N^h_{Dt}} = (\tilde{z}^h_{Dt})^k(\tilde{z}^h_{Xjt})^k$ $\frac{N^i_{Xht}}{N^i_{Dt}} = (\tilde{z}^i_{Dt})^k(\tilde{z}^i_{Xht})^k$ $\frac{N^i_{Xjt}}{N^i_{Dt}} = (\tilde{z}^i_{Dt})^k(\tilde{z}^i_{Xjt})^k$ $\frac{N^j_{Xht}}{N^j_{Dt}} = (\tilde{z}^j_{Dt})^k(\tilde{z}^j_{Xht})^k$ $\frac{N^j_{Xit}}{N^j_{Dt}} = (\tilde{z}^j_{Dt})^k(\tilde{z}^j_{Xit})^k$
Zero Profit Condition For Domestic Firms	$\tilde{d}^h_{Dt} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^h f_D^h}{Z_t^h}$ $\tilde{d}^i_{Dt} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^i f_D^i}{Z_t^i}$ $\tilde{d}^j_{Dt} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^j f_D^j}{Z_t^j}$
Zero Profit Condition For Exporting Firms	$\tilde{d}^h_{Xit} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^h f_{Xi}^h}{Z_t^h}$ $\tilde{d}^h_{Xjt} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^h f_{Xj}^h}{Z_t^h}$ $\tilde{d}^i_{Xht} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^h f_{Xh}^i}{Z_t^h}$ $\tilde{d}^i_{Xjt} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^h f_{Xj}^i}{Z_t^h}$ $\tilde{d}^j_{Xht} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^h f_{Xh}^j}{Z_t^h}$ $\tilde{d}^j_{Xit} = (\theta-1)\left(\frac{\nu^{\theta-1}}{k}\right)\frac{w_t^h f_{Xi}^j}{Z_t^h}$
Household Bond Euler Equation	$(C_t^h)^{-\gamma} = \beta(1+r_t^h)E_t[(C^h_{t+1})^{-\gamma}]$ $(C_t^i)^{-\gamma} = \beta(1+r_t^i)E_t[(C^i_{t+1})^{-\gamma}]$ $(C_t^j)^{-\gamma} = \beta(1+r_t^j)E_t[(C^j_{t+1})^{-\gamma}]$
Household Share Euler Equation	$\tilde{v}_t^h = \beta(1-\delta)E_t\left[\frac{C^h_{t+1}}{C^h_t}^{-\gamma}(\tilde{v}^h_{t+1} + \tilde{d}^h_{t+1})\right]$ $\tilde{v}_t^i = \beta(1-\delta)E_t\left[\frac{C^i_{t+1}}{C^i_t}^{-\gamma}(\tilde{v}^i_{t+1} + \tilde{d}^i_{t+1})\right]$ $\tilde{v}_t^j = \beta(1-\delta)E_t\left[\frac{C^j_{t+1}}{C^j_t}^{-\gamma}(\tilde{v}^j_{t+1} + \tilde{d}^j_{t+1})\right]$
Labour Market Clearing Equation	$L_t^h = L^h_{Pt} + \left(\frac{E(z^h_{Dt+1})}{z^h_{min}}\right)^k \frac{N^h_{Et}f^h_{Et}}{Z_t^h} + \frac{N^h_{Dt}f^h_{Dt}}{Z_t^h} + \frac{N^h_{Xit}f^h_{Xit}}{Z_t^h} + \frac{N^h_{Xjt}f^h_{Xjt}}{Z_t^h}$ $L_t^i = L^i_{Pt} + \left(\frac{E(z^i_{Dt+1})}{z^i_{min}}\right)^k \frac{N^i_{Et}f^i_{Et}}{Z_t^i} + \frac{N^i_{Dt}f^i_{Dt}}{Z_t^i} + \frac{N^i_{Xht}f^i_{Xht}}{Z_t^i} + \frac{N^i_{Xjt}f^i_{Xjt}}{Z_t^i}$ $L_t^j = L^j_{Pt} + \left(\frac{E(z^j_{Dt+1})}{z^j_{min}}\right)^k \frac{N^j_{Et}f^j_{Et}}{Z_t^j} + \frac{N^j_{Dt}f^j_{Dt}}{Z_t^j} + \frac{N^j_{Xht}f^j_{Xht}}{Z_t^j} + \frac{N^j_{Xit}f^j_{Xit}}{Z_t^j}$
Balanced Trade Equation	$Q_t^i N^h_{Xit}(\tilde{\rho}^h_{Xit})^{1-\theta}C_t^i + Q_t^j N^h_{Xjt}(\tilde{\rho}^h_{Xjt})^{1-\theta}C_t^j =$ $N^i_{Xht}(\tilde{\rho}^i_{Xht})^{1-\theta}C_t^h + N^j_{Xht}(\tilde{\rho}^j_{Xht})^{1-\theta}C_t^h$ $1/Q_t^i N^i_{Xht}(\tilde{\rho}^u_{Xht})^{1-\theta}C_t^h + Q_t^j/Q_t^i N^i_{Xjt}(\tilde{\rho}^i_{Xjt})^{1-\theta}C_t^j =$ $N^h_{Xit}(\tilde{\rho}^h_{Xit})^{1-\theta}C_t^i + N^j_{Xit}(\tilde{\rho}^j_{Xit})^{1-\theta}C_t^i$

Table B2: Parameter Values Used in the Model Calibration

Parameter	Value	Description
β	0.99	Household discount factor
γ	2	Risk aversion
δ	0.0235	Probability of firm death
θ	3.8	Elasticity of substitution
k	3.4	Firm-level productivity dispersion
ρ	0.9	Aggregate persistence
z^h_{min}	1	Minimum firm productivity in country h
z^i_{min}	1	Minimum firm productivity in country i
z^j_{min}	1	Minimum firm productivity in country j
f^h_E	1	Firm sunk entry cost in country h
f^i_E	1	Firm sunk entry cost in country i
f^j_E	1	Firm sunk entry cost in country j
f^h_D	0.0090	Per period fixed cost of producing for the domestic market in country h
f^i_D	0.0104	Per period fixed cost of producing for the domestic market in country i
f^j_D	0.0184	Per period fixed cost of producing for the domestic market in country j
τ^h_i	1.316	Per unit iceberg cost of exporting from country h to country i
τ^h_j	1.450	Per unit iceberg cost of exporting from country h to country j
τ^i_h	1.326	Per unit iceberg cost of exporting from country i to country h
τ^i_j	1.450	Per unit iceberg cost of exporting from country i to country j
τ^j_h	1.459	Per unit iceberg cost of exporting from country j to country h
τ^j_i	1.459	Per unit iceberg cost of exporting from country j to country i
f^h_{Xi}	0.09	Per period fixed cost of producing for the country i export market in country h
f^h_{Xj}	0.082	Per period fixed cost of producing for the country j export market in country h
f^i_{Xh}	0.083	Per period fixed cost of producing for the country h export market in country i
f^i_{Xj}	0.135	Per period fixed cost of producing for the country j export market in country i
f^j_{Xh}	0.136	Per period fixed cost of producing for the country h export market in country j
f^j_{Xi}	0.136	Per period fixed cost of producing for the country i export market in country j
L^h	1	Size of country h
L^i	5.93	Size of country i
L^j	19.59	Size of country j

Appendix C

Appendices to Chapter 5

Table C1: Baseline Regression Country List

Acronym	Country	EU Member	2017 IMF Global GDP Rank
AUS	Australia	No	13
AUT	Austria	Yes	28
BEL	Belgium	Yes	25
BGR	Bulgaria	Yes	78
BRA	Brazil	No	8
CAN	Canada	No	10
CHE	Switzerland	No (Bilateral Agreements)	20
CHN	China, People's Republic of	No	2
CYP	Cyprus	Yes	110
CZE	Czech Republic	Yes	49
DEU	Germany	Yes	4
DNK	Denmark	Yes	36
ESP	Spain	Yes	14
EST	Estonia	Yes	103
FIN	Finland	Yes	44
FRA	France	Yes	7
GBR	United Kingdom	Yes	5
GRC	Greece	Yes	53
HRV	Croatia	Yes	79
HUN	Hungary	Yes	58
IDN	Indonesia	No	16
IND	India	No	6
IRL	Ireland	Yes	35
ITA	Italy	Yes	9
JPN	Japan	No	3
KOR	Republic of Korea	No	11
LTU	Lithuania	Yes	86
LUX	Luxembourg	Yes	73
LVA	Latvia	Yes	99
MEX	Mexico	No	15
MLT	Malta	Yes	129
NLD	Netherlands	Yes	18
NOR	Norway	No (EEA)	29
POL	Poland	Yes	24
PRT	Portugal	Yes	47
ROU	Romania	Yes	50
RUS	Russian Federation	No	12
SVK	Slovakia	Yes	65
SVN	Slovenia	Yes	84
SWE	Sweden	Yes	23
TUR	Turkey	No	17
TWN	Taiwan	No	22
USA	United States of America	No	1

Table C2: Sub-Sample Industry List

ISIC Code	Industry	5% Tradeable	10% Tradeable	10% Goods	Costinot *et al.* (2012)	Manufacturing	Services	5% Services	10% Services
01	Crop and Animal	Yes	No	No	No	No	No	No	No
02	Forestry	Yes	Yes	Yes	No	No	No	No	No
03	Fishing	Yes	Yes	Yes	No	No	No	No	No
B	Mining	Yes	Yes	Yes	No	No	No	No	No
10-12	Food Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
13-15	Textile Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
16	Wood Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
17	Paper Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
18	Printing	Yes	No	No	No	Yes	No	No	No
19	Petroleum Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
20	Chemical Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
21	Pharmaceuticals	Yes	Yes	Yes	No	Yes	No	No	No
22	Rubber Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
23	Non-Metallic Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
24	Basic Metal Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
25	Fabricated Metals	Yes	Yes	Yes	No	Yes	No	No	No
26	Computer Manufacturing	Yes	Yes	Yes	No	Yes	No	No	No
27	Electrical Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
28	Machinery Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
29	Motor Vehicle Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
30	Transport Manufacturing	Yes	Yes	Yes	No	Yes	No	No	No
31-32	Furniture Manufacturing	Yes	Yes	Yes	Yes	Yes	No	No	No
33	Repair and Installation	Yes	No	No	No	No	No	No	No
D	Electricity and Gas Supply	No	No	No	No	No	No	No	No
36	Water Treatment and Supply	No	No	No	No	No	Yes	No	No
37-39	Waste Management Services	Yes	Yes	No	No	No	Yes	Yes	Yes
F	Construction	No	No	No	No	No	Yes	No	No
45	Motor Vehicle Trade	No	No	No	No	No	Yes	No	No
46	Wholesale Trade (Non-Motor)	Yes	Yes	No	No	No	Yes	Yes	Yes
47	Retail Trade (Non-Motor)	No	No	No	No	No	Yes	No	No
49	Land Transport	Yes	Yes	No	No	No	Yes	Yes	No
50	Water Transport	Yes	Yes	No	No	No	Yes	Yes	Yes
51	Air Transport	Yes	Yes	No	No	No	Yes	Yes	Yes
52	Warehousing	Yes	Yes	No	No	No	Yes	Yes	Yes
53	Postal and Couriers	Yes	Yes	No	No	No	Yes	Yes	No

ISIC Code	Industry	5% Tradeable	10% Tradeable	10% Goods	Costinot *et al.* (2012)	Manufacturing	Services	5% Services	10% Services
I	Accommodation and Food	Yes	Yes	No	No	No	Yes	Yes	No
58	Publishing Activities	Yes	Yes	No	No	No	Yes	Yes	Yes
59-60	Multimedia Activities	Yes	Yes	No	No	No	Yes	Yes	No
61	Telecommunications	No	No	No	No	No	Yes	No	No
62-63	Computer Services	Yes	Yes	No	No	No	Yes	Yes	Yes
64	Financial Services	Yes	Yes	No	No	No	Yes	Yes	No
65	Insurance Services	Yes	Yes	No	No	No	Yes	Yes	No
66	Auxiliary Services	Yes	Yes	No	No	No	Yes	Yes	Yes
L	Real Estate Activities	No	No	No	No	No	Yes	No	No
69-70	Legal and Accounting	Yes	Yes	No	No	No	Yes	Yes	No
71	Engineering Services	Yes	Yes	No	No	No	Yes	Yes	Yes
72	Research and Development	Yes	Yes	No	No	No	Yes	Yes	No
73	Advertising	Yes	Yes	No	No	No	Yes	Yes	No
74-75	Other Scientific	Yes	Yes	No	No	No	Yes	Yes	No
N	Administrative Services	Yes	Yes	No	No	No	Yes	Yes	Yes
O	Public Administration	No	No	No	No	No	Yes	No	No
P	Education	No	No	No	No	No	Yes	No	No
Q	Health Services	No	No	No	No	No	Yes	No	No
R-S	Other Services	No	No	No	No	No	Yes	No	No
T	Household Activities	No	No	No	No	No	Yes	No	No
U	Extraterritorial	No	No	No	No	No	Yes	No	No

Table C3: Sub-Sample Country List

Acronym	Country	Costinot *et al.* (2012)	Single Market	EU	Non-EU	Top 20 by GDP
AUS	Australia	Yes	No	No	Yes	Yes
AUT	Austria	No	Yes	Yes	No	No
BEL	Belgium	Yes	Yes	Yes	No	No
BGR	Bulgaria	No	Yes	Yes	No	No
BRA	Brazil	No	No	No	Yes	Yes
CAN	Canada	No	No	No	Yes	Yes
CHE	Switzerland	No	Yes	No	No	Yes
CHN	China	No	No	No	Yes	Yes
CYP	Cyprus	No	Yes	Yes	No	No
CZE	Czech Republic	Yes	Yes	Yes	No	No
DEU	Germany	Yes	Yes	Yes	No	Yes
DNK	Denmark	Yes	Yes	Yes	No	No
ESP	Spain	Yes	Yes	Yes	No	Yes
EST	Estonia	No	Yes	Yes	No	No
FIN	Finland	Yes	Yes	Yes	No	No
FRA	France	Yes	Yes	Yes	No	Yes
GBR	United Kingdom	Yes	Yes	Yes	No	Yes
GRC	Greece	Yes	Yes	Yes	No	No
HRV	Croatia	No	Yes	Yes	No	No
HUN	Hungary	Yes	Yes	Yes	No	No
IDN	Indonesia	No	No	No	Yes	Yes
IND	India	No	No	No	Yes	Yes
IRL	Ireland	Yes	Yes	Yes	No	No
ITA	Italy	Yes	Yes	Yes	No	Yes
JPN	Japan	Yes	No	No	Yes	Yes
KOR	Republic of Korea	Yes	No	No	Yes	Yes
LTU	Lithuania	No	Yes	Yes	No	No
LUX	Luxembourg	No	Yes	Yes	No	No
LVA	Latvia	No	Yes	Yes	No	No
MEX	Mexico	Yes	No	No	Yes	Yes
MLT	Malta	No	Yes	Yes	No	No
NLD	Netherlands	Yes	Yes	Yes	No	Yes
NOR	Norway	No	Yes	No	No	No
POL	Poland	Yes	Yes	Yes	No	No
PRT	Portugal	Yes	Yes	Yes	No	No
ROU	Romania	No	Yes	Yes	No	No
RUS	Russian Federation	No	No	No	Yes	Yes
SVK	Slovakia	Yes	Yes	Yes	No	No
SVN	Slovenia	No	Yes	Yes	No	No
SWE	Sweden	Yes	Yes	Yes	No	No
TUR	Turkey	No	No	No	Yes	Yes
TWN	Taiwan	No	No	No	Yes	No
USA	United States of America	No	No	No	Yes	Yes