Essays on macro-labour and uncertainty

Myrto Oikonomou

Merton College

University of Oxford

A thesis submitted for the degree of

Doctor of Philosophy in Economics

Trinity Term 2021

In memory of my loving grandfather Michalis
Στη μνήμη του αγαπημένου μου παππού Μιχάλη

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This dissertation consists of three self-contained chapters which discuss topics related to macro-labour and uncertainty. Chapter 1 examines the impact of cross-border migration on business cycle dynamics and focuses on the implications of brain-drain for origin countries. Through the lens of an open-economy DSGE model that features endogenous migration flows, trade linkages, search frictions, and skill heterogeneity, I study the quantitative impact of cyclical migration in Greece during the European Debt Crisis. I find that rather than stabilising the Greek business cycle, migration led to a deeper and more protracted recession, primarily due to the negative effects it had on the skill composition of the domestic workforce and investment. Chapter 2 explores the role of labour market frictions and specifically the role of endogenous job destruction for the propagation of uncertainty shocks. To address this topic, I build a DSGE model with search and matching frictions, price rigidities and time-varying stochastic volatility, and I calibrate the model to US data. I find that endogenous job separations play an important amplification role for uncertainty shocks. I also find that the introduction of endogenous match separations can challenge the widely-held perception that uncertainty shocks behave like negative aggregate demand shocks, as the behaviour of inflation hinges on the specification of the Taylor rule. Finally, Chapter 3 analyses the impact of uncertainty shocks on firm entry, trade and labour markets through the lens of a DSGE model with endogenous producer entry. I find that contrary to models with a fixed mass of producers, precautionary savings propagate uncertainty shocks through two distinct mechanisms. The first one is the aggregate demand mechanism which is at play in models without endogenous firm entry. The second channel however, arises from the interplay of precautionary behaviour and endogenous firm entry. Precautionary savings from households lead to higher entry of relatively less productive non-trading firms, driving down aggregate productivity and creating inflationary pressures.

Supervisor This thesis was supervised by Professor Andrea Ferrero.

Total words This thesis contains approximately 51,705 words. This word count has been calculated by counting the number of words on a representative page (383 words, page 2) and multiplying this with the number of pages, excluding the cover and table of contents.

Note for the reader Several derivations for the stated equations can be found in the appendix. The appendix also contains detailed calibration tables for each chapter of this thesis.

Statement of authorship The work in this thesis is based solely on research carried out by me as a student at the University of Oxford between October 2016 and July 2021. No part of this thesis has been submitted for a degree at the University of Oxford or any other university. Chapters 1, 2 and 3 are single-authored and are fully my own work. This work has benefited greatly from the feedback, the discussions and the very warm hospitality offered by the Bank of England during my placement as the David Walton Scholar, and from the Danish National Bank and the St. Louis Federal Reserve during my stints as an academic visitor.

Acknowledgement of funding I very gratefully acknowledge funding from the Economics and Social Research Council (for the academic years 2016/2018), the David Walton Distinguished Doctoral Scholarship (for the academic year 2018/2019), the Onassis Foundation (for the academic year 2019/2020) and the Doctoral Completion Bursary from Merton College (for the year 2021).

Acknowledgements

Even though I am concluding my academic journey in this strange post-pandemic period, I cannot help but feel deeply thankful for having had so much support in the past years, and for being part of the wonderful Oxford research community.

To my supervisor, Andrea Ferrero: thank you for your guidance, for your invaluable advice throughout this journey and for always challenging me to become a better researcher and improve. And thank you wholeheartedly for supporting me in making the first steps towards the next professional adventure. To Harris Dellas: thank your for tirelessly supporting me and for your words of wisdom and kindness. You have been more than a valuable mentor in these past years. To Francesco Zanetti: thank you for all our discussions, for your valuable advice and your sound support and encouragement throughout my doctoral research and the job market.

I must also thank those who advised and guided me inside and outside of Oxford, and in particular Michalis Rousakis, for being a mentor and a friend in Merton and beyond, Björn van Roye for his invaluable support and advice, and Michael McMahon and Petr Sedláček for their insightful feedback and discussions.

To the wonderful people that made the Econ Department feel like family and the SSL feel like (almost) home, Rajssa and Alex, thank you for sharing the good and the bad days of this journey with me and above all for your friendship, and Genevieve, Lukas, Madhav, Simon and Timo, Jemima, Tatjana, Vanessa and Samantha thank you for your inspiration, and for the days of laughter and the days of stress we shared. I cherish all our moments together.

I am also thankful to my dearest friends outside the econ crew. To old friends, Maria, Nikoleta, Xristina and Zina, thank you for always being there for me and always believing in me, it means more than you know. To Paris, thank you for your love and for your support in the early steps of the DPhil. And to new friends, Marionette, thank you for making the days at Oxford and beyond so full of colour and fun. Valaki, thank you for each and every discussion we've had that always left me full of warmth and hope, Aloni, Marie, Sam, Sam and Suzanne thank you for being so wonderful housemates and friends and Marios and the rest of the OUGS crew thank you for all the times you cheered me up. And to Matina and Jeremy thank you for keeping me sane throughout the pandemic and job market blues.

To Konstantinos, thank you with all my heart for sharing this adventure with me, for always being there to give me a hug when I needed it and for making the good days so much better and the bad ones, at least good in terms of food. You made these past years so bright and beautiful.

To my family, my wonderful parents, my loving sister Nafsika and my dear grandparents, without whom I would not have embarked on this journey: thank you for everything. This thesis and all that came with it, was only possible because I had you and your love along each step of the road. This is dedicated to you and to my loving grandfather Michalis, who I lost in the final years of the DPhil, but will always thank for guiding me in this adventure and the ones that lie ahead.

Αυτή η διδακτορική διατριβή είναι αφιερωμένη στην οικογένειά μου και στον παππού μου, που μου έμαθε πώς να εκτιμώ τις αξίες της ζωής και τον ευχαριστώ για όλα.

Myrto Oikonomou
Oxford, July 2021

Contents

List of Figures

CHAPTER 1

Migration, search and skill heterogeneity

Abstract Cross-border migration can act as an important adjustment mechanism to country-specific shocks. Yet, depending on who moves, it can have unintended consequences for business cycle stability. This paper argues that the skill composition of migration plays a critical role. When migration flows become more concentrated in skilled labour an important trade-off arises. On the one hand, migration releases unemployment pressures for the origin countries. On the other hand, it generates negative compositional effects (the so-called "brain drain" effects") and skill imbalances, which reduce supply capacity in origin countries. This paper analyses quantitatively the impact of cyclical migration in an open-economy DSGE model with endogenous migration flows, trade linkages, search and matching frictions, and skill heterogeneity. I apply this framework to the case of the Greek emigration wave following the European Debt Crisis. What I find is that emigration flows implied strong negative effects for capital formation, leading to a more than 15% drop in investment relative to a no-migration counterfactual. Rather than stabilising the Greek business cycle, labour mobility led to a deeper and more protracted recession.

1.1 Introduction

The 2010 Sovereign Debt Crisis exposed the Euro Area to a severe asymmetric shock, leading to divergent macroeconomic behaviour between the European core and periphery country members. Against the backdrop of mounting borrowing costs, a severe deterioration of the labour market conditions and a steep drop in economic activity, the capacity of European periphery countries to employ countercyclical macroeconomic tools was limited. The absence of the option to devaluate national currencies removed an important adjustment mechanism. At the same time, the austerity measures imposed in several Southern European countries meant that national fiscal policy had limited space for manoeuvring. Against limited alternative adjustment mechanisms, cross-border emigration flows from the European periphery to core countries surged (Figure 1.1, a).[1] However, contrary to previous migration waves, this one was characterised by a significant shift in the skill-content of labour flows (Figure 1.1, b).

Can migration indeed stabilise the business cycle of origin countries? How does the skill composition of migration flows impact the shock–absorbing capacity of migration? This paper sets out to address these questions through the lens of a small open economy Dynamic Stochastic General Equilibrium (DSGE) model. The main finding is that the nature of migration flows in terms of skills is important for the stabilising role of migration. Contrary to conventional wisdom, migration can have a destabilising impact on the business cycle due to adverse effects on the incentives for capital accumulation and on supply capacity.

Labour mobility has been identified as a key adjustment mechanism to asymmetric shocks in the context of currency unions, and it is one of the preconditions for an optimal currency area according to the seminal work of Mundell (1961). When the relative factor prices and the nominal exchange rate cannot adjust in response to idiosyncratic shocks, mobility of production factors offers an alternative. Cross-border labour mobility in particular can stabilise labour market conditions in the country hit by the idiosyncratic shock. Emigration endogenously

[1]For the case of Greece, the country that experienced the deepest and most protracted recession, emigration flows resulted in more than 7% of active population exiting the country between 2010 and 2015 (Bandeira et al., 2019). For Spain, emigration flows were unprecedented as well, amounting to outflows close to 1% of total population over 2010 - 2014 (Izquierdo et al., 2016).

reduces the pool of unemployed thereby mitigating the increase in unemployment rates and the negative wage pressure in domestic labour markets. Additionally, cross-border migration allows consumption smoothing through remittances, which can act as a risk-sharing device.[2] In many ways, the increase in emigration from periphery countries during the Sovereign Debt crisis can be characterised as a Mundellian automatic stabiliser. Yet, this analysis of cyclical migration overlooks an important factor: skill heterogeneity. Gross migration flows from the Euro Area periphery to core countries mask important heterogeneity in terms of the educational profile of emigrants, which shifted in the recent migration wave.[3]

With heterogeneous labour flows, cross-country migration changes not only the size of the workforce in the origin country but also its skill composition. In this paper, I argue that the resulting skill imbalances can have a negative impact on firms' investment decisions leading to lower economic activity and reversing the cushioning effect of migration. To quantify the effects of cyclical migration, I build a DSGE model which features two types of household (high and low skilled), and explicitly accounts for the compositional ("brain drain") effects of migration. The model has three key frictions. Firstly, search and matching frictions which generate equilibrium unemployment and are asymmetric among the two types of workers. Secondly, a migration choice which endogenously changes over the business cycle depending on relative labour market conditions in origin and destination countries and mobility costs which differ across the two households. Thirdly, capital-skill complementarities in the production function, which introduce a link between capital demand and the skill content of the labour force.

I apply this framework to the case of Greece, focusing on the emigration wave

[2]However, we should note that remittances are of minor quantitative significance for Southern European countries. Based on World Bank data, the average share of remittances over GDP for 2010-2015 was 0.82% for the European South. For comparison, the world average over the same period was 4.7%, as this insurance mechanism plays a much more prominent role for developing and frontier economies.

[3]For the case of Greece, Labrianidis and Pratsinakis (2016) report that approximately 65% of total migration outflows post 2010 were highly educated graduates. These findings are confirmed by own research. Based on LFS and population registry data from the German microcensus and the Danish statistical office, I find a shift in the skill content of both immigrant flows and stocks from the European periphery to Germany and Denmark respectively. While the rising educational attainment in origin countries can partially offset the negative compositional effects of emigration, the growth of high-skilled emigration outpaced dramatically the increase in tertiary educated domestic workforce (see Appendix 1).

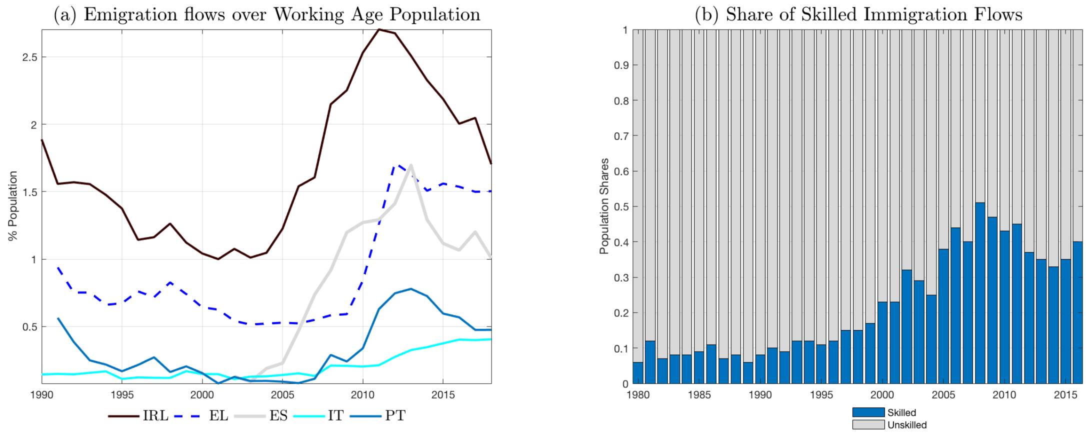

Figure 1.1: Emigration flows, evolution of size and skill composition

Notes: (a) Gross emigration flows from European periphery countries as a % share of total working age population (years 15-64). See Appendix 1 for net emigration flows. (b) Immigration flows from periphery (Ireland, Greece, Spain, Italy and Portugal) to Germany. Skill classification is via educational attainment (ISCED level 5 and above). The sample is controlled for working age at year of entry (years 25-64 to account for education-related migration). See Appendix 1 for alternative skill classifications.
Sources: Eurostat and German Microcensus.

during the Sovereign Debt crisis. I find that, for realistic degrees of capital skill complementarity in the production technology, skill-specific labour shortages due to migration outflows had a significant negative effect on capital accumulation and production. Comparing the baseline scenario to a counterfactual scenario of no migration, the output trough is lower by more than 7 percentage points, the investment trough by more than 15 percentage points, and consumption, despite an initially smaller drop (due to the risk-sharing effects of migration), exhibits a trough which is almost 5 percentage points lower.

The interaction between labour market externalities, due to search frictions, and production externalities, due to the capital-skill complementarity, is crucial for this result. The production externality reduces the incentive of firms to invest in capital when emigration flows are skewed towards the highly skilled. If capital is more productive when coupled with skilled labour, then a lower stock of skilled workers will reduce the returns on investment. The drop in capital demand is magnified due to search frictions and the heterogeneous mobility costs among the two skill types. Skilled households face lower mobility costs resulting in relatively more skilled unemployed directing their search abroad. As a result, market tightness for the skilled increases and the effective costs of skilled vacancies go up. Firms' incentive to post skilled vacancies are muted further amplifying the reduction in capital demand. The combined effect of lower total labour supply and lower relative share of skilled labour supply due to migration generates a sharp and persistent drop in output and exacerbates rather than dampens the recessionary shock.

This paper proceeds as follows. Section 1.2 briefly discusses the related literature. Section 1.3 presents the model and Section 1.4 presents the calibration strategy. Section 1.5 continues with the quantitative analysis of the model and section 1.6 concludes.

1.2 Related literature

This paper relates to two strands of literature. Firstly, it contributes to the literature on cyclical migration. Following the increase of intra-Euro Area migration flows, there has been growing academic interest in studying how migration matters for the business cycle dynamics of Euro Area countries, as well as for monetary and fiscal policy. The paper that is the closest to my study is Bandeira et al. (2019). Similarly to the present paper, the authors look at Greek outflows in a small open economy model that combines search and matching frictions and endogenous labour mobility, but with a different focus. The authors examine the link between fiscal austerity and migration and uncover a novel bi-directional relationship. Fiscal consolidations, especially when conducted through labour tax hikes intensify emigration. In turn, emigration reduces the tax base at the origin country and leads to higher and more persistent consolidations in order to meet given fiscal targets. Even though the interaction between migration and fiscal policy is highly important, our study abstracts from this dimension. It introduces heterogeneity in migration flows and focuses on the compositional effects of migration due to "brain-drain".

This paper is also related to House et al. (2018). The authors provide empirical evidence that European net migration, in line with the predictions of Mundell's framework, responded strongly to the growing cross-country unemployment differentials during the Sovereign Debt crisis. The authors estimate a multi-country

DSGE model that features frictional labour markets and internal migration. They find that labour mobility is effective in reducing cross-country unemployment and per capita GDP differentials and can substitute independent monetary policy in delivering the necessary adjustment.

In another related paper, Hauser and Seneca (2019) study the implications of labour mobility for the monetary authorities of a currency union. The authors build a two-region DSGE model with sticky prices and market inefficiencies. They find that migration by endogenously stabilising regional labour market conditions can ease the unemployment–inflation tradeoff of the monetary policy maker. They also study the implications of internal migration for optimal monetary policy and argue that in the presence of labour mobility, strict inflation targeting is suboptimal whereas a higher weight on labour market developments in the policy rule is welfare-improving.

Cyclical migration and its impact on destination countries has also gained increasing academic interest. Lozej (2019) study the effects of a positive migration shock in a DSGE model with frictional labour markets that is calibrated to the Irish economy. Similarly to this study, he finds that migration amplifies business cycle fluctuations to country-specific shocks. Smith and Thoenissen (2018) address a similar question focusing on the New Zealand economy. The authors estimate an open economy DSGE model with physical capital, human capital and housing. A key finding of their paper is that the differences in human capital levels between migrants and locals are critical for the business cycle impact of migration. This result is consistent with the findings of this paper. However, differently to Smith and Thoenissen (2018), this paper focuses on an origin country and explicitly accounts for the interplay between search frictions and the compositional effects of migration.

There have also been several empirical studies that assess the impact of migration shocks. Furlanetto and Robstad (2019) use Norwegian data in a structural VAR model, and find evidence that migration shocks are an important driver of unemployment dynamics, leading to lower unemployment rates for both the native and the total population. In a similar vein, Faccioli and Vella (2020) use recent data on net migration from Germany, and find that migration shocks had an expansionary effect on investment, output per capita, net exports and tax revenues. The authors also report differential impact of migration shocks on native and immigrant unemployment. They report that net migration shocks had a positive effect on job creation, driving down unemployment for natives but increasing competition for immigrant workers and subsequently causing their unemployment rate to increase.

The second strand of literature that our analysis relates to is research on capital-skill complementarities. Griliches (1969) stated the hypothesis that capital is less substitutable for skilled labour than for unskilled labour, and following his seminal work several studies have found supporting empirical evidence in favour of this hypothesis. Krusell et al. (2000) used U.S. data to estimate a more general production function that allowed for capital-skill complementarities, and found that capital equipment is more complementary with skilled labour than unskilled labour. They also showed that this hypothesis is critical in order to explain the pattern of skill premia in the US economy. In related work, Maliar et al. (2020) tested the capital-skill complementarity hypothesis extending the dataset in Krusell et al. (2000) to include more recent data (over 1993-2017) and confirmed the original findings.

Several studies have tested the capital-skill complementarity hypothesis for European countries as well. Lindquist (2005) uses Swedish data and finds that similarly to Krusell et al. (2000), skilled labour and capital equipment are complementary factor inputs, whereas unskilled labour and capital equipment are substitutes for one another. Batista (2007) tests this hypothesis for the case of the Portuguese economy and also finds evidence in favour of capital-skill complementarity in the aggregate production technology. Using a cross-sectional panel (that includes Greece and several other Euro Area countries) Duffy et al. (2004) also find some support in favour of the capital-skill complementarity hypothesis, although their evidence is weaker than country-specific studies and the required threshold for skilled labour is lower compared to Krusell et al. (2000).

In a study that relates to this paper, Dolado et al. (2021) embed the capital-skill complementarity framework in a closed economy New Keynesian model with search and matching frictions, in order to study the distributional effects of monetary policy. This paper follows a similar modelling approach but in an open economy model that features changes in the skill composition of the domestic workforce due to heterogeneous migration flows.

1.3 Model

1.3.1 Model overview

I build a small open economy model which features two types of household (high and low skilled), search and matching frictions and endogenous migration. A combination of location preferences and a pecuniary cost to migrate micro-founds migration flows. The production technology is characterized by capital-skill complementarity, as in Krusell et al. (2000). The model also features a remittance channel, trade links, investment adjustment costs and real rigidities in order to capture empirically relevant features of the business cycle dynamics. These modelling choices allow me to study the aggregate and distributional impact of emigration in a unified way. Figure 1.2 illustrates the key features of the model.

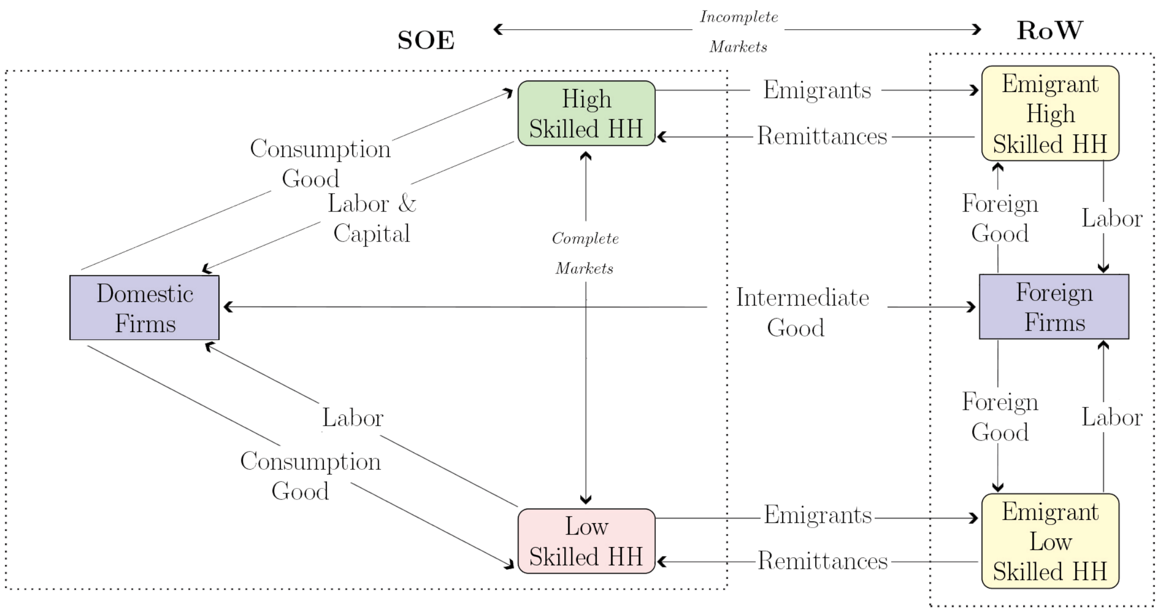

Figure 1.2: Model overview

1.3.2 Labour markets

The small open economy (henceforth SOE) is populated by two household types. Type h, which supplies high–skilled labour, and type l, which supplies low–skilled labour. I assume that the mass of each household type stays constant and I denote with M_i the respective measure of household type i, for $i \in h, l$.[4] I also assume that the skill type of each household member is fixed (there is no transitioning across the different households) and that markets are segmented. The total population mass is normalised to one, i.e., $\sum_{i\in\{h,l\}} M_i = 1$. At any point in time, there are three different labour market status that a household member can occupy: employment at home $N^r_{i,t}$, employment abroad $N^e_{i,t}$, and unemployment $U_{i,t}$.

$$M_{i,t} = N^r_{i,t} + N^e_{i,t} + U_{i,t} \ , i \in \{h, l\} \ . \tag{1.1}$$

Unemployed workers can choose where to search. A share $\mu_{i,t}$ of the stock of unemployed, $U_{i,t}$, choose to search abroad, while the remaining search in the domestic market. A key assumption is that unemployed members "search from home" following empirical evidence in support of remote search (Redding and Rossi-Hansberg, 2017). The share of emigrant searchers, $\mu_{i,t}$, is an endogenous object of the model and differs across household types. Importantly, if separated from their job at Foreign, emigrant household members return to Home, thereby receiving the domestic unemployment benefits. This assumption will allow us to focus the analysis on work–related migration and implies that both emigrant and resident workers face the same outside option. The latter will play a role during the bargaining stage.

The matching process between workers and firms is costly in terms of time and resources due to matching frictions. These matching frictions generate positive involuntary unemployment in equilibrium, and give rise to a match surplus that agents divide among themselves based on a wage setting specification. The matching technology which captures search frictions, is modified to reflect the migration

[4] An alternative modelling choice would be to introduce population growth dynamics and assume that emigration changes the total mass of household types. However, given the emphasis of the paper on cyclical migration, I maintain the assumption of constant measure for both skill types.

choice of household members in the following way

$$m_{i,t} = \chi_i (V_{i,t})^{1-\epsilon_i} ((1-\mu_{i,t})\, U_{i,t})^{\epsilon_i} \;, i \in \{h, l\} \;, \tag{1.2}$$

where $m_{i,t}$ denotes the new matches for each skill type i, χ_i is the matching efficiency, ϵ_i is the elasticity of new matches with respect to searching workers, and $V_{i,t}$ denotes the vacancies posted by firms.

The transition probabilities associated with the matching function are modified in a similar way. The job–finding probability, $f_{i,t}$, the job–filling probability, $q_{i,t}$ and labour market tightness, $\theta_{i,t}$, are defined as follows

$$f_{i,t} \equiv \frac{m_{i,t}}{((1-\mu_{i,t})U_{i,t})} \;, \tag{1.3}$$

$$q_{i,t} \equiv \frac{m_{i,t}}{V_{i,t}} \;, \tag{1.4}$$

$$\theta_{i,t} \equiv \frac{V_{i,t}}{((1-\mu_{i,t})U_{i,t})} \;, i \in \{h, l\} \;. \tag{1.5}$$

We follow the timing convention used in Sala et al. (2008) and assume that new matches become productive with a lag. Under this time–to–build assumption, the mass of resident and emigrant employed workers evolves according to the following laws of motion

$$N^r_{i,t+1} = (1-\rho_i) N^r_{i,t} + f_{i,t}(1-\mu_{i,t}) U_{i,t} \;, \tag{1.6}$$

$$N^e_{i,t+1} = (1-\rho^\star_i) N^e_{i,t} + f^\star_{i,t} \mu_{i,t} U_{i,t} \;, i \in \{h, l\} \;, \tag{1.7}$$

where ρ_i is the exogenous separation probability of a match. The law of motion of emigrant workers depends on the foreign separation rate, $\rho^\star_i$, and the foreign job–finding rate, $f^\star_{i,t}$, which the SOE takes as given.[5]

[5]While the domestic job-finding rate, $f_{i,t}$, is determined in equilibrium, the SOE has no impact on foreign labour market conditions which are taken as exogenous processes. This is a reasonable assumption even in the presence of large migration outflows if their relative size compared to the destination country labour force is small (e.g., due to dispersed search across several destination countries).

1.3.3 Households

The two household types share certain common features. Both type of agents derive utility from consumption and they incur a disutility cost when members of the household work abroad. I follow the large family framework of Andolfatto (1996) and subsequent literature, which allows me to abstract from heterogeneity due to changes in the employment status or location of work when deriving the intertemporal consumption–saving decisions of the household.[6]

The disutility cost that household members suffer is proportional to the size of the emigrant stock. This cost captures location preferences, which are a key building block in quantitative models of economic geography (Redding and Rossi-Hansberg, 2017; Kennan and Walker, 2011) and have become a common practice in business cycle models with labour mobility (Bandeira et al., 2019; House et al., 2018; Sterk, 2015). These preferences capture in a reduced form way the attachment of household members to the Home location due to higher utility from local amenities, the lack of language and cultural barriers or lower informational frictions regarding labour market conditions (Kaplan and Schulhofer-Wohl, 2017).

High–skilled Households

The representative high–skilled household maximises the expected lifetime utility function subject to the budget constraint, the law of motion of capital and the laws of motion of emigrant and resident employment. Given the assumption of perfect risk–sharing among household members and the constant household mass assumption, the optimisation problem of the household can be recast in per capita terms as follows

$$\underbrace{\max}_{c_{h,t},\mu_{h,t},k_{t+1},d^{\star}_{t+1}} \quad \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left(\log(c_{h,t} - \xi \overline{c}_{h,t-1}) - \Omega_h n^e_{h,t} \right) \ , \tag{1.8}$$

where $c_{h,t}$ is the per capita consumption of the household members, (I will henceforth denote with small–case letters the variables in per–capita terms), ξ gov-

[6]The large family assumption is equivalent to the existence of complete markets at the household level, which allow for perfect risk–sharing among emigrants and residents, as well employed and unemployed members. This assumption adds tractability to the optimisation problem of the household as the relevant stochastic discount factor is the same for all household members. Under the alternative specification where the emigrant members cease to be part of the domestic household, they would also adopt the foreign stochastic discount factor.

erns habits, the term $\bar{c}_{h,t-1}$ captures aggregate last period consumption (which the household members take as given), $n^e_{h,t}$ is the relative measure of skilled emigrants and Ω_h governs the moving disutility. The flow budget constraint is given by

$$\begin{aligned} c_{h,t} + i_t + Q_t R_t d^\star_t + \frac{\mathit{\Gamma}_h}{2}\left(\frac{\mu_{h,t}\, u_{h,t}}{\mu_{h,t-1}\, u_{h,t-1}} - 1\right)^2 \mu_{h,t}\, u_{h,t} \\ = R^k_t k_t + Q_t d^\star_{t+1} + w_{h,t} n^r_{h,t} + Q_t w^\star_{t,h}\, n^e_{h,t} + \phi_h u_{h,t} + t_{h,t} + div_t \end{aligned} \tag{1.9}$$

where i_t is investment, Q_t is the real exchange rate and $d^\star_t$ is the debt position of the household from trading an international non–state contingent bond. In each period, a share $\mu_{h,t} u_{h,t}$ of household members emigrates and the household pays additionally to the disutility cost, a pecuniary moving cost governed by parameter $\mathit{\Gamma}_h$. These pecuniary costs will be critical for matching the dynamics of emigration flows and differ by skill type. Household members can be employed at Home, $n^r_{h,t}$, earning labour income $w_{h,t}$, employed at Foreign, $n^e_{h,t}$, earning real-exchange-rate-adjusted foreign wage, $Q_t\, w^\star_{t,h}$, or unemployed earning unemployment benefit ϕ_h.[7] Apart from earning labour income, the household rents capital k_t to firms, issues debt $d^\star_{t+1}$, pays lump–sum taxes $t_{h,t}$ and receives dividend income from firm ownership div_t. R^k_t and R_t are the rental rate of capital and the gross returns on holding domestic debt.

Capital stock evolves according to the following law of motion

$$k_t = (1-\delta) k_{t-1} + \left(1 - \frac{\Xi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2\right) i_t\ , \tag{1.10}$$

where δ is the depreciation rate and parameter Ξ controls the investment adjustment costs.

Low–skilled Households

Low–skilled households face a similar problem to the high–skilled households (see Appendix 1 for the remaining optimality conditions of both households). For

[7] Emigrants workers receive the same wage as native foreign workers as I abstract from issues related to immigrant assimilation and/or labour misallocation. This assumption hinges on the degree of substitutability between migrant and native workers within skill type, which has been an object of controversy in the literature (e.g., see the debate between Ottaviano and Peri (2012) and Borjas et al. (2008)). However, in the context of intra–Euro Area migration, the assumption of perfect substitutability seems reasonable to maintain. The foreign wages $w^\star_{i,t}$ are taken as given by the household.

tractability reasons only high–skilled households have firm and capital ownership and access to international financial markets. However, under the baseline model with complete domestic financial markets, the above assumptions have little impact for the per capita consumption of the low–skilled, which perfectly co–moves with the high–skilled per capita consumption based on the following risk–sharing condition

$$\Lambda^c_{l,t} = \tilde{\Theta}\Lambda^c_{h,t} \ , \tag{1.11}$$

where $\Lambda^c_{l,t}$ is the marginal utility of consumption for low–skilled households, $\Lambda^c_{h,t}$ is the marginal utility of consumption for high–skilled households and $\tilde{\Theta}$ captures the initial wealth distribution.

Moving choice

While domestic and emigrant employment are determined by their respective laws of motion as the outcome of search and matching frictions, the share of unemployed who direct their search abroad, $\mu_{i,t}$, is determined by the optimality conditions of the household. The representative household manager compares the relative labour market conditions at Home and Foreign taking into account the utility and pecuniary moving costs. The moving costs are only worth paying if the wage and job–finding rate differentials between the two regions are large enough. In the model, this is captured by the following arbitrage condition

$$\begin{aligned}\underbrace{f^{\star}_{i,t}\,\Lambda^e_{i,t} - f_{i,t}\,\Lambda^r_{i,t}}_{\text{Net gain from search abroad}} \;=\; & \Lambda^c_{i,t}\left(\frac{\mathit{\Gamma}_i}{2}\left(\frac{\mu_{i,t}u_{i,t}}{\mu_{i,t-1}u_{i,t-1}}-1\right)^2 + \mathit{\Gamma}_i\left(\frac{\mu_{i,t}u_{i,t}}{\mu_{i,t-1}u_{i,t-1}}-1\right)\frac{\mu_{i,t}u_{i,t}}{\mu_{i,t-1}u_{i,t-1}} + \right.\\ & \underbrace{\beta\mathbb{E}_t\Lambda^c_{i,t+1}\mathit{\Gamma}_i\left(\frac{\mu_{i,t+1}u_{i,t+1}}{\mu_{i,t}u_{i,t}}-1\right)\left(\frac{\mu_{i,t+1}u_{i,t+1}}{\mu_{i,t}u_{i,t}})^2\right)}_{\text{Moving costs}} \ ,\end{aligned} \tag{1.12}$$

where $\Lambda^r_{i,t}$ denotes the net marginal value of a domestically employed worker and $\Lambda^e_{i,t}$ is the net marginal value of an emigrant worker. $\Lambda^r_{i,t}$ comprises of two terms: the expected flow value that a job match generates net of foregone unemployment benefits and the capital gains of an additional worker conditional on the job match surviving. The associated Bellman equation is

$$\Lambda^r_{i,t} \equiv \frac{\partial\mathcal{L}_{i,t}}{\partial n^r_{i,t+1}} = \beta\mathbb{E}_t\Lambda^c_{i,t+1}\left(w_{i,t+1}-\phi_i\right) + (1-\varrho_i - f_{i,t+1})\Lambda^r_{i,t+1}\big) \ i \in \{h,l\} \ . \tag{1.13}$$

$\Lambda^e_{i,t}$ is similar but there is an additional component which captures the utility costs associated with migration

$$\Lambda^e_{i,t} \equiv \frac{\partial \mathcal{L}_{i,t}}{\partial n^e_{i,t+1}} = -\beta\Omega_i + \beta\mathbb{E}_t\Lambda^c_{i,t+1}\left(Q_{t+1}w^\star_{i,t+1} - \phi_i\right) \\ + \beta\mathbb{E}_t(1-\varrho^\star_i)\Lambda^e_{i,t+1} - \beta\mathbb{E}_t f_{i,t+1}\Lambda^r_{i,t+1} \ . \tag{1.14}$$

1.3.4 Production

Production follows a layered structure. There are different firm types, which are all owned by the high–skilled household. In the first stage of production, a continuum of perfectly competitive firms hire high and low skilled labour and capital and produce a homogeneous tradeable intermediate good. This is the stage at which search and matching frictions occur and wage bargaining takes place. In the second stage, a representative firm bundles the intermediate home and foreign tradeable goods into the final good X_t, which is then used for resident consumption, C^r_t, investment I_t, and government spending G_t.

Final good firms

The representative final good firm aggregates the domestic and foreign intermediate goods $X_{d,t}$ and $X_{f,t}$ according to the following CES technology

$$X_t = \left(\omega^{\frac{1}{\theta}} X_{d,t}^{\frac{\theta-1}{\theta}} + (1-\omega)^{\frac{1}{\theta}} X_{f,t}^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}} \ ,\theta > 0 \ ,\omega \in (0,1) \ , \tag{1.15}$$

where parameter ω captures the degree of home bias in the small open economy and θ the elasticity of substitution between domestic and foreign goods. The associated price index is

$$P_t = \left(\omega\, \varrho_{d,t}^{1-\theta} + (1-\omega)\ \varrho_{f,t}^{1-\theta}\right)^{\frac{1}{1-\theta}} \ , \tag{1.16}$$

where $\varrho_{d,t}$ and $\varrho_{f,t}$ are the relative prices of the domestic and foreign good. The representative firm takes prices as given and maximises profits $\Pi_t = X_t - \varrho_{d,t}\, X_{d,t} - \varrho_{f,t}\, X_{f,t}$, which yields the following optimal demand schedules

$$X_{d,t} = \omega\, \varrho_{d,t}^{-\theta}\, X_t \ , \tag{1.17}$$

$$X_{f,t} = (1-\omega)\ \varrho_{f,t}^{-\theta} X_t \ . \tag{1.18}$$

Intermediate good firm

The wholesale intermediate good firm combines labour inputs with capital and faces frictional labour markets. I adopt a more general two-layer CES technology that nests the standard Cobb–Douglas production function, following Krusell et al. (2000)

$$\begin{aligned} y_t^h &= A_t \left(s_s S_t^{\nu} + (1 - s_s) N_{l,t}^{r\ \nu} \right)^{\frac{1}{\nu}} \ , \\ S_t &= \left(s_k K_t^{\gamma} + (1 - s_k)(N_{h,t}^r)^{\gamma} \right)^{\frac{1}{\gamma}} \ , \\ s_k \ , s_s &\in (0,1) \ , \gamma \ , \nu \in (-\infty, 1) \ \text{ and } \ \gamma \ , \nu \neq 0 \ , \end{aligned} \tag{1.19}$$

where A_t is the exogenous neutral technology process, y_t^h is the domestic intermediate good production and S_t is the skilled composite input good. The parameters that govern the elasticity of substitution between input factors are γ and ν. The elasticity of substitution between high–skill labour and capital is equal to $1/(1-\gamma)$, whereas the elasticity of substitution between low–skill labour and capital (which is identical to the elasticity of substitution between the two labour types) is equal to $1/(1-\nu)$. The parameters s_s and s_k control the income share of low–skill labour and capital respectively. The key feature of this encompassing production technology is that for $\nu > \gamma$ capital–skill complementarities arise, whereas when either $\nu \to 0$ or $\gamma \to 0$ we can retrieve the Cobb–Douglas function.

Wholesale firms decide how many vacancies to post and how much capital to rent by solving the following dynamic cost minimization problem (note that they have the same stochastic discount factor as the high–skilled households)

$$\underbrace{\min}_{v_{h,t}, v_{l,t}, k_t} \ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_{h,t+1}^c}{\Lambda_{h,t}^c} \left(p_t^w y_t^h - r_t^K K_t - w_{h,t} N_{h,t}^r - w_{l,t} N_{l,t}^r - \kappa_h v_{h,t} - \kappa_l v_{l,t} \right) \ , \tag{1.20}$$

subject to their production technology (1.19) and the laws of motion of employment

$$N_{i,t+1}^r = (1 - \rho_i) N_{i,t}^r + q_{i,t} v_{i,t}, \tag{1.21}$$

for $i \in \{h, l\}$,where $q_{i,t}$ is the probability of filling a vacancy for skill type i, p_t^w is the relative price of the wholesale goods in terms of the final good and κ_i is the vacancy posting cost. The first–order condition for vacancies combined with the free entry condition of firms yield the job creation schedule

$$\frac{\kappa_i}{q_{i,t}} = \beta \mathbb{E}_t \frac{\Lambda^c_{h,t+1}}{\Lambda^c_{h,t}} \left(p^w_{t+1} F^n_{i,t+1} - w_{i,t+1} + (1-\varrho_i) \frac{\kappa_i}{q_{i,t+1}} \right) . \tag{1.22}$$

Firms post vacancies until the expected marginal cost of posting a vacancy, i.e., the real posting cost κ_i times the expected duration that the vacancy remains unfilled $1/q_{i,t}$, is equal to the expected marginal benefit, i.e., the net revenue created by an additional worker and the expected continuation value of the match which survives with probability $(1-\rho_i)$. The variable $F^n_{i,t}$ denotes the marginal product of labour of skill type i. The differences in the marginal labour productivity and in the search frictions that workers face will determine how skill premia evolve.

Wage schedule

With frictional labour markets workers and firms hold monopoly power due to search costs, which include the vacancy posting costs, as well as foregone wages and production. As a result, each job match involves an economic rent which is split between workers and firms according to some surplus sharing rule.

Below I define the value functions that enter the surplus sharing rule. Let $\mathcal{J}_{i,t}$ denote the value of a filled vacancy of skill type i for the representative firm

$$\mathcal{J}_{i,t} = p^w_t F^n_{i,t} - w_{i,t} + (1-\varrho_i)\mathbb{E}_t \beta \frac{\Lambda^c_{h,t+1}}{\Lambda^c_{h,t}} \mathcal{J}_{t+1} . \tag{1.23}$$

If the firm successfully fills a vacancy, it obtains the net flow profit of the match and the continuation value conditional on match survival. Let $\mathcal{V}^n_{i,t}$ denote the value of a match for a domestic worker in utility adjusted terms. The associated Bellman equation is

$$\mathcal{V}^n_{i,t} \equiv \frac{\Lambda^n_{i,t}}{\Lambda^c_{i,t}} = w_{i,t} - \phi_i + \beta \mathbb{E}_t \frac{\Lambda^c_{i,t+1}}{\Lambda^c_{i,t}} (1-\varrho_i - f_{i,t}) \mathcal{V}^n_{i,t+1} . \tag{1.24}$$

Wages are determined as the outcome of a Nash bargaining problem that maximises the weighted product of firm and households' match surplus

$$\underbrace{\max}_{w^n_{i,t}}, = \left(\mathcal{V}^n_{i,t}\right)^{\psi_i} \left(\mathcal{J}_{i,t}\right)^{1-\psi_i} , \tag{1.25}$$

where $\psi_i \in (0, 1)$ is the worker's relative bargaining power. The Nash–bargained wage is defined as

$$w^n_{i,t} = (1 - \psi_i) \left(p^w_t F^n_{i,t} + \kappa_i \theta_{i,t}\right) + \psi_i \phi_i \ . \tag{1.26}$$

As in Hall (2005), I introduce real wage rigidities in the labour market by assuming the following adaptive rule [8]

$$w_{i,t} = (w_{i,t-1})^{\gamma_w} \left(w^n_{i,t}\right)^{1-\gamma_w} \ , \tag{1.27}$$

where γ_w denotes the degree of real wage rigidity.

Fiscal policy

The government pays unemployment benefits and consumes G_t of final goods (which I assume to be a constant fraction g of GDP in every period) and levies lump–sum taxes. The period–by–period constraint of the government is described as follows

$$G_t + \sum_{i \in \{h,l\}} \phi_i U_{i,t} = \sum_{i \in \{h,l\}} M_i t_{i,t} \tag{1.28}$$

1.3.5 Market clearing

Market clearing in the intermediate goods market requires production to equal total demand for domestic intermediate goods

$$y^h_t = X_{d,t} + X^\star_{d,t} \ , \tag{1.29}$$

where foreign aggregate demand $X^\star_{d,t}$ is given by the following schedule

$$X^\star_{d,t} = (1 - \omega^\star) \left(\frac{\varrho_{d,t}}{Q_t}\right)^{-\theta^\star} X^\star_t \ . \tag{1.30}$$

The real exchange rate is defined as $Q_t = \frac{P^\star_t}{P_t}$. The parameters $\theta^\star$ and $\omega^\star$ are the foreign counterparties for the elasticity of substitution and home bias. The structure

[8] The introduction of real wage rigidities is one way to address the well documented "Shimer's puzzle" i.e., the unrealistically high stability in the vacancy and unemployment rates generated in the canonical search and matching model (Shimer, 2005). With sticky wages, firms can extract a larger share of the match surplus. As a result, vacancy posting and unemployment rates become more sensitive to changes in the underlying shocks. These rigidities capture in a reduced form a range of imperfections related to institutional or legal frictions in the labour market.

of the foreign economy is similar to the home economy but due to the small size of the latter, domestic developments have a negligible effect in foreign economy dynamics. As a result, $X^{\star}_t$, which denotes the foreign GDP, is taken as exogenous.

For final good market clearing it is useful to rewrite the consolidated budget constraint (1.9) in terms of the budget constraint of the emigrants and residents. Starting with the constraint of residents (the budget constraint for the low–skilled, which is analogous, is presented in Appendix 1)

$$\begin{aligned}(u_{h,t}+n^r_{h,t})c^r_{h,t}+i_t+Q_tR_td^{\star}_t+\frac{\Gamma_h}{2}\left(\frac{\mu_{h,t}\,u_{h,t}}{\mu_{h,t-1}\,u_{h,t-1}}-1\right)^2\mu_{h,t}\,u_{h,t}\\ =R^k_tk_t+Q_td^{\star}_{t+1}+w_{h,t}n^r_{h,t}+\underbrace{Q_tZ_{h,t}n^e_{h,t}}_{\text{remittances}}+\phi_hu_{h,t}+t_{h,t}+div_t\end{aligned} \tag{1.31}$$

where $c^r_{h,t}$ is consumption of the domestic final good and $Z_{h,t}$ are per capita remittances which are in terms of the foreign final good. Remittances are pinned down by the budget constraint of emigrants who send a constant fraction of their labour income back home, and allocate the remaining amount to foreign good consumption $c^e_{h,t}$[9]

$$c^e_{h,t}n^e_{h,t}=w^{\star}_{h,t}n^e_{h,t}-Z_{h,t}n^e_{h,t}=(1-\zeta)w^{\star}_{h,t}n^e_{h,t}\ . \tag{1.32}$$

Market clearing for final goods implies

$$X_t=\sum_{i\in\{h,l\}}(N^r_{i,t}+U_{i,t})c^r_{i,t}+\sum_{i\in\{h,l\}}\frac{\Gamma_i}{2}\left(\frac{\mu_{i,t}\,u_{i,t}}{\mu_{i,t-1}\,u_{i,t-1}}-1\right)^2\mu_{i,t}\,u_{i,t}+\sum_{i\in\{h,l\}}\kappa_iv_{i,t}+I_t+G_t\ . \tag{1.33}$$

Further, the trade balance is defined in units of the final good as follows

$$TB_t=\varrho_{d,t}X^{\star}_{d,t}-\varrho_{f,t}X_{f,t}\ , \tag{1.34}$$

and GDP is defined as

$$p^y_tY_t=\sum_{i\in\{h,l\}}(N^r_{i,t}+U_{i,t})c^r_{i,t}+I_t+G_t+TB_t\ , \tag{1.35}$$

where p^y_t is the real GDP deflator. Taking into account the market clearing conditions for the different markets and aggregating the budget constraint for both households we can obtain the law of motion of net foreign assets as

$$Q_tR_tD^{\star}_t=Q_tD^{\star}_{t+1}+TB_t+Q_t(Z_{h,t}N^e_{h,t}+Z_{l,t}N^e_{l,t})\ , \tag{1.36}$$

[9]Note that total per capita consumption, which is the relevant optimisation object, is derived as the residual of (1.9) and (1.31). It is given by $c_{h,t}=(u_{h,t}+n^r_{h,t})c^r_{h,t}+Q_tn^e_{h,t}c^e_{h,t}$.

where $D_t^\star = M_h d_t^\star$. The known issue of non–stationarity that arises in the SOE is addressed by assuming the following debt–elastic interest rate [10]

$$R_t = R_t^\star + \chi_t \ , \tag{1.37}$$

where $R_t^\star$ is the foreign interest rate which the SOE takes as given and χ_t is the risk–premium it pays

$$\chi_t = \Psi \left(\exp \left(\frac{Q_t D_{t+1}^\star}{gdp_t} - \frac{Q D^\star}{gdp} \right) - 1 \right) + \epsilon_t^{rp} \ , \tag{1.38}$$

where ϵ_t^{rp} denotes the risk premium shock.

1.4 Calibration

The model is calibrated to match salient features of the Greek economy prior to the Euro Area debt crisis. For conventional parameters I follow closely the Bank of Greece small open economy DSGE framework (Papageorgiou, 2014). For less conventional parameters, such as labour market institutional features, I target related moments of the Greek economy. Table 1.D in Appendix 1 summarizes the calibration strategy. The calibration is at an annual frequency.

Preferences The subjective discount factor is set to $\beta = 0.96$ so that the model is consistent with a long–run annual real interest rate of 4%. I set the parameter that controls habit formation ξ to 0.6 following Papageorgiou (2014). The parameters Ω_i which control the disutility of moving are set to jointly match an implied steady state share of total emigrant stock equal to 8% and a relative share of skilled emigrants equal to 35%.[11] Turning to the pecuniary costs, $\mathit{\Gamma}_i$, which discipline the response of emigration flows to the recessionary shock, I jointly target the total cumulative outflows between 2010 and 2015, amounting to 7% of working age population according to (Bandeira et al., 2019), and an average skill to unskilled

[10]The steady state level of net foreign asset holdings is not pinned down by the equilibrium conditions in the small open economy. Instead there are multiple steady states depending on the initial conditions of net foreign assets. As a result, temporary shocks can have permanent effects on the level of variables creating a unit–root problem in equilibrium dynamics. Assuming debt–elastic interest rates is one way of circumventing the non–stationarity.

[11]This is the 2000–2009 average emigrant stock in Euro Area countries based on the International Migration Database of OECD. The targeted relative share of skilled emigrants is the 2000–2009 average share based on the German Microcensus data.

ratio of 2/3 over the same period. The latter is in line with survey data evidence from Labrianidis and Pratsinakis (2016) who report that more than 65% of Greek emigrants post 2010 were highly educated graduates (as measured by ISCED levels of 5 and above).

Production I set the parameters that govern the capital–labour complementarity following Krusell et al. (2000). Specifically, γ is set to match an elasticity of substitution between skilled labour and capital equal to $\rho_{k,h} = 0.67$, and ν is set to match an elasticity of substitution between unskilled labour and capital equal to $\rho_{k,l} = 1.67$. The income share parameters s_k and s_s are calibrated to match the Greek capital income share $r^k_t K_t / gdp_t = 0.36$ (based on Papageorgiou (2014)) and the skilled labour share $w_{h,t} N_{h,t} / gdp_t = 16\%$ based on EUKLEMS data. I follow Chodorow-Reich et al. (2019) and set the elasticity of substitution between foreign and domestic intermediate goods to $\theta = 1.65$. Home bias is equal to $\omega = 0.75$ as in Bandeira et al. (2019). Even though these values are targeted to Greek trade data they are very close to values used conventionally in the open economy literature (see for instance Backus et al. (1994)). The depreciation rate is set to $\delta = 8\%$, in line with Chodorow-Reich et al. (2019), and the parameter governing the investment adjustment costs is set to $\Xi = 0.9$ following Papageorgiou (2014).

Labour Market and Demographics The relative mass of the high–skilled household is set to match the share of working age population with tertiary education as reported in ELSTAT. For the matching efficiency parameters I target the skill–specific unemployment rate for the period 2000–2009 (7% and 12% for high and low skilled respectively) based on Eurostat. The resulting values imply higher matching efficiency for skilled. Separation rates are set to $\rho_h = \rho_l = 8\%$ following Hobijn and Sahin (2009), who estimate transition rates for several OECD countries, including Greece.[12] I set the steady state job–filling probabilities equal to $q_h = 0.7$ and $q_l = 0.6$, which are comparable to the values in Pappa et al. (2015). This calibration strategy pins down the vacancy posting costs and yields total vacancy costs equal to 4% of the GDP. This number is on the high

[12]Even though data on skill–specific separation rates are not available our calibration does deliver different job–finding probabilities across households.

end but consistent with the literature (Trigari, 2009). Moreover, this calibration strategy implies that search frictions are relatively higher for the low–skilled who face lower job–finding probabilities and are characterized by lower matching efficiency. The combination of lower job–filling rates and higher vacancy posting costs for the low-skilled increases the effective hiring cost in that market segment. However, the low–skilled are relatively more abundant. As a result, there is more slack in their market, which puts downward pressure on their wages. This acts as a counterweight for firms which can extract a relatively larger share of the match surplus in the low–skill segment. The match elasticities with respect to searchers are set to $\epsilon_h = 0.6$ and $\epsilon_l = 0.4$. These values are within the range of plausible elasticities reported in the Pissarides and Petrongolo (2001) survey. Moreover, I assume that the decentralised equilibrium is socially efficient which equates the worker's bargaining power ψ_i to their respective match elasticities ϵ_i (see Hosios (1990)). The unemployment benefits for skilled and unskilled are set to match an average replacement rate of 65% based on the OECD "Benefits and Wages" data on Greece (Christoffel et al. (2009)). The parameter that governs real wage rigidities is equal to $\gamma_w = 0.65$ following Papageorgiou (2014).

Foreign The labour market conditions at Foreign enter the optimal search decision of the households who compare regional differences on unemployment and job–finding rates. I calibrate the relevant foreign labour market variables to match German data given that Germany was the most popular Euro Area destination country for Greek emigrants. I target foreign unemployment rate of 4% for high-skilled and 8% for low–skilled based on Eurostat. I set the separation rate equal to $\rho^\star = 0.13$ following Hobijn and Sahin (2009). Wage differentials between Home and Foreign are based on EUKLEMS data prior to 2010. Finally, ζ which is controlling for remittances is calibrated to target a total share over GDP equal to 0.3%, based on World Bank data.

1.5 Quantitative analysis

I first evaluate the quantitative implications of migration by studying the dynamic adjustment of the model economy to a negative risk–premium shock under two scenarios. The baseline scenario features an outflow of high and low–skilled labour in line with what we observed in the data. In the counterfactual scenario, the option to emigrate is shut down. The shock is calibrated to generate an initial drop in aggregate resident consumption consistent with the data (household consumption dropped by 6.8% y.o.y in 2010).

An important takeaway from this exercise is that contrary to the conventional wisdom, migration amplified the effects of the recessionary shock. This experiment confirms previous findings in the cyclical migration literature (Bandeira et al. (2019), Lozej (2019)), and it provides novel insight into how amplification differs across skill–specific variables. The model is approximated to a first order around its deterministic steady state and the shock path is kept constant across the different scenarios.

The amplifying role of migration

As shown in Figure 1.3, the initial response of consumption is similar under both model scenarios, in line with the calibration strategy. Facing higher risk–premia, households reduce debt issuance which leads to a compression in aggregate demand and a drop in consumption. For the first three years, when the rate of migration outflows is the highest, resident consumption performs marginally better in the presence of migration. This can be explained by the increase in remittances which help to relax the budget constraint of the residents. Despite a similar initial response, the consumption paths differ significantly in terms of dynamics, with consumption being more persistent under the baseline scenario. This can be traced to the deeper and more protracted contraction of production in the presence of migration.

Firms respond to lower aggregate demand by reducing vacancy postings, causing unemployment to increase and wages to fall. Because mobility costs are lower for the high–skilled, emigration flows are larger and peak earlier for skilled labour. This has severe negative effects for investment and capital accumulation. The contraction in investment is much more pronounced under migration because the shrinking relative stock of skilled labour implies that capital becomes less productive. Indeed, an important difference between the two scenarios is the different trajectory of the marginal product of capital.

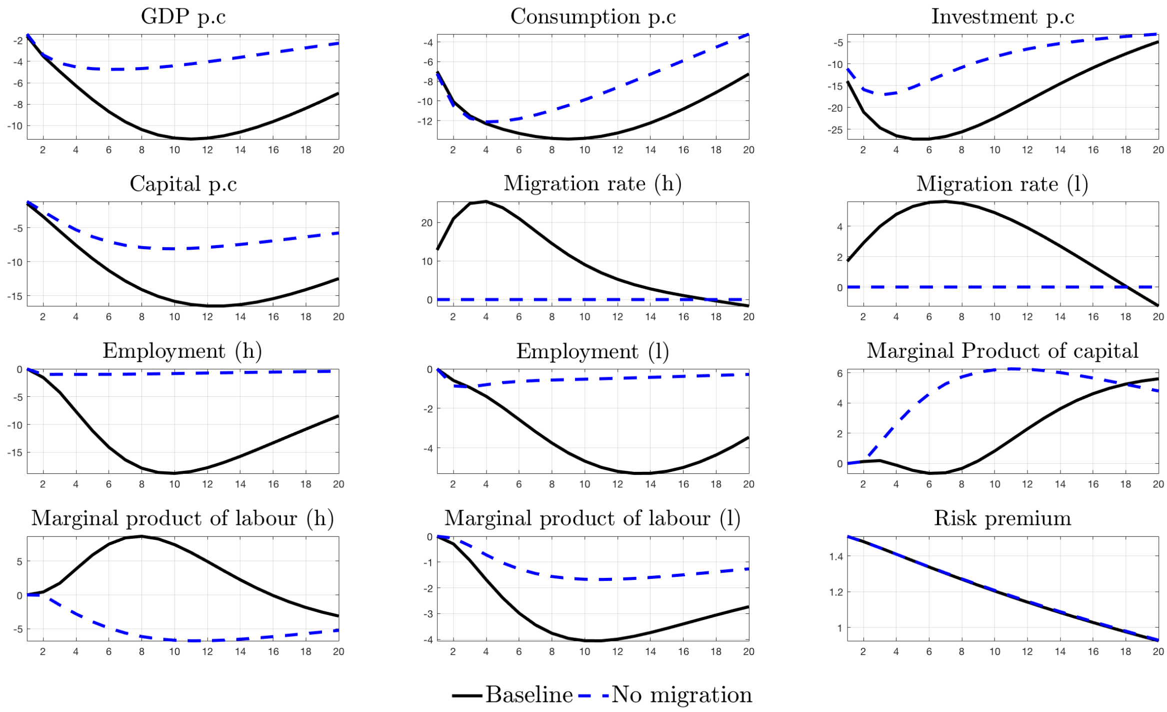

Figure 1.3: Impact of risk premium shock (a)

Note: Impulse Response Functions to a negative risk-premium shock. IRFs are in terms of % deviations from steady state with the exception of unemployment rates and the real exchange rate which are in absolute deviations from steady state. The parenthesis terms refer to skilled households (h) and unskilled households (l). The horizontal axis depicts years.

Migration does stabilise domestic unemployment as Figure 1.4 shows. However, this cushioning effect is temporary and differs across skill types.[13] For the skilled households, that are more mobile and also face higher job–finding rates at Foreign, unemployment rate in fact drops. For the unskilled households, the cushioning effects of migration kick in with delay due to their higher adjustment costs, and are less sizeable. Once migration outflows reverse, the unemployment rate increases for both households.

The asymmetric emigration flows imply different responses of key labour market variables for the skilled and unskilled households. Firms face a higher effective cost of posting vacancies in the skilled segment because they compete over a smaller pool of domestic skilled searchers. As a result, emigration amplifies the

[13]Figure 1.4 reports total unemployment rates, i.e., it includes unemployed searchers who are looking for jobs abroad. For the dynamics of unemployment that excludes search at Foreign see Appendix 1.

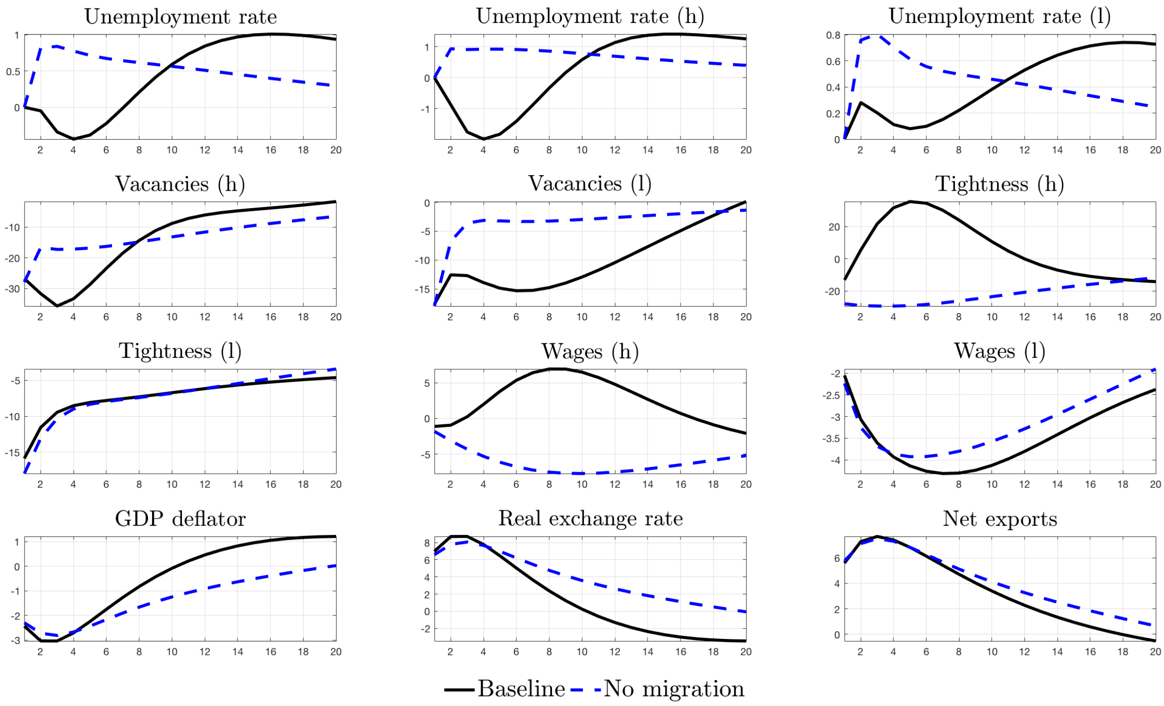

Figure 1.4: Impact of risk premium shock (b)

Note: Impulse Response Functions to a negative risk-premium shock. IRFs are in terms of % deviations from steady state with the exception of unemployment rates and the real exchange rate which are in absolute deviations from steady state. The parenthesis terms refer to skilled households (h) and unskilled households (l). The horizontal axis depicts years.

reduction in vacancies for the skilled. In contrast, the unskilled who are less mobile, face a reduction in vacancies that is closer to the no–migration scenario. The dynamics of tightness differ in an analogous way.

Wages also respond very differently for skilled and unskilled. For the skilled, wages increase in sharp contrast with the no–migration scenario. For the unskilled, wages experience an even steeper reduction compared to the no–migration scenario. This divergent behaviour of wages has two key drivers. Firstly, the asymmetric response of tightness. Secondly, the starkly different response of the marginal product of labour. The decrease in domestic labour supply is pushing the marginal product of labour up for both skill types. However, the reduction of capital has a countervailing effect.Due to the relative scarcity of skilled labour, the former dominates for skilled whereas the latter is stronger for the unskilled, causing wages to diverge.

Interestingly, migration has a mitigating effect on the external adjustment of the economy. Under both scenarios, the real exchange rate depreciates in response to the risk premium shock due to the negative price pressures. This in turn induces an expenditure switching effect which drives up net exports as domestic tradeable goods become relatively cheaper. However, in the presence of migration the decrease in relative prices is less pronounced due to lower adjustment of high–skilled wages. Migration essentially implies that the origin economy cannot export its way out of the crisis to the same degree as in the no–migration case.

As Figure 1.5 shows, heterogeneous migration outflows have aggregate as well as distributional effects. In the absence of migration, the risk–premium shock drives skill premia down because the skilled workers suffer a larger drop in their productivity as firms also reduce demand for the complementary capital. However, under the baseline scenario the mass exit of skilled workers drives skill premia to the opposite direction. This sharp increase in skill premia is sufficient to generate higher income inequality, compared to the no–migration scenario. Indeed, the response in the relative income share is muted under migration despite the fact that skilled employment contracted significantly more.[14].

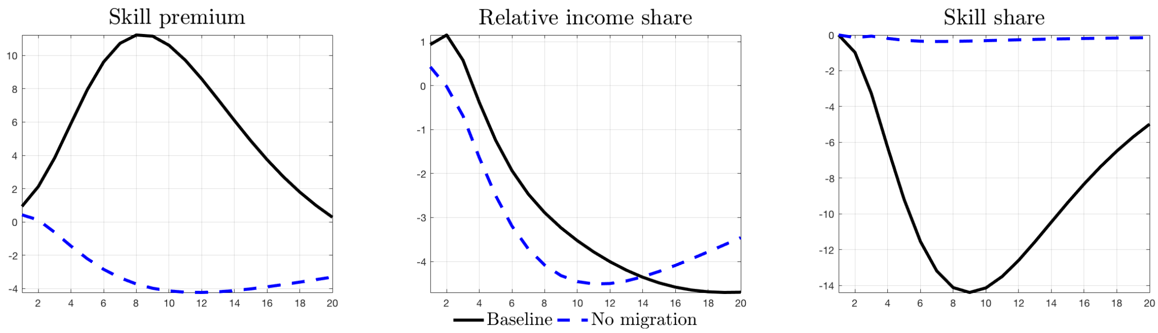

Figure 1.5: Impact of risk premium shock (c)

Note: Impulse Response Functions to a negative risk–premium shock. IRFs are in terms of % deviations from steady state. Relative income share refers to the income share of skilled workers over unskilled workers. Skill share refers to the ratio of skilled to unskilled workforce. The horizontal axis depicts years.

[14]The income shares are defined as $\frac{w_i N_i^r}{gdp - \sum_{i \in \{h,l\}} \kappa_i V_i}$

Who leaves matters

In the previous experiment, the amplifying role of emigration can be traced to two underlying channels: changes in the size of the domestic workforce and changes in its skill composition. To better distil the role of heterogeneity in migration flows, I repeat this exercise but restricting the moving choice to one skill group for each scenario.

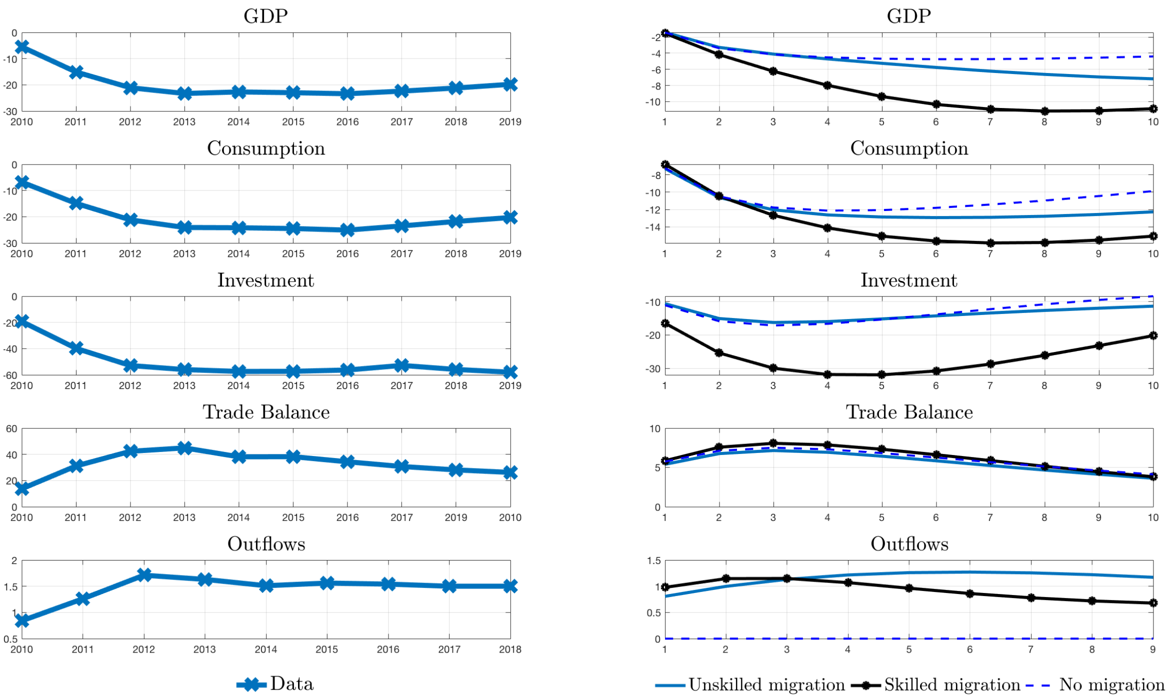

Figure 1.6: Data vs model dynamics

Note: Impulse Response Functions to a negative risk-premium shock. The data series are in % deviations from their 2009 values apart from outflows. Measurements are in chain linked volumes (2010). Model responses are in % deviations from steady state apart from outflows. Outflows are in % of total working age population.
Source: ELSTAT.

Figure 1.6 presents the responses of key macroeconomic variables to the same negative risk–premium shock when migration is shut down for both skill types, when it is an option for only skilled searchers and when only unskilled searchers can move. This allows us to separately identify the impact of migration outflows from each group. Figure 1.6, compares the model responses (right column) to data (left column). The goal of this exercise is not to replicate exactly the historical path of the variables, but rather to uncover the relative importance of the compositional effects of migration. In the data series, consumption refers to total final consumption expenditure of households, investment to gross fixed capital formation and trade balance to net exports of goods. All variables are in aggregate terms.

Despite outflows being comparable in terms of size under the two migration scenarios, the contraction of the GDP and its main components differs substantially in magnitude and persistence. The main driver of this result lies in the different response of investment. When only the unskilled have the option to emigrate, the reduction in investment is muted, and tracks closely the investment response under the no–migration scenario. This is not the case under the skilled emigration scenario when investment suffers a much steeper drop. The trough–to–trough difference between the two migration scenarios is more than 20%.

To understand the differences in the response of investment, it is important to note the interplay between the two externalities that the model features. Firstly, the production externality implies that firms' demand for capital differs depending on who leaves. When it is skilled labour who emigrates, the change in the skill ratio of the domestic workforce leads to a lower marginal productivity of capital due to capital skill complementarities, and dampens capital demand. This drop is further amplified due to the second externality in the model, which originates in the labour market. In the presence of search and matching frictions, asymmetric emigration will lead do different degrees of congestion in the skilled and unskilled market segments. When only skilled workers emigrate, the relatively higher competition among firms in the skilled segment mitigates their hiring incentives. Lower vacancy posting for skilled workers leads to further deterioration of the workforce composition and intensifies the reduction in capital demand.[15]

This is evident in Figure 1.7, which compares the amplifying effect of migration under different model specifications. This figure plots the differences in impulse response functions to a negative risk premium shock with and without migration. I gradually turn off the key frictions of the model in order to investigate their relative importance and interactions. The different lines refer to the baseline model spec-

[15]Note that in the decentralised equilibrium with emigration an important inefficiency arises. When household members decide where to direct their search they don't internalise the impact of their choice on aggregate labour market tightness (see Hosios (1990) for related discussion). As a result, they fail to fully account for how their choice impacts capital formation.

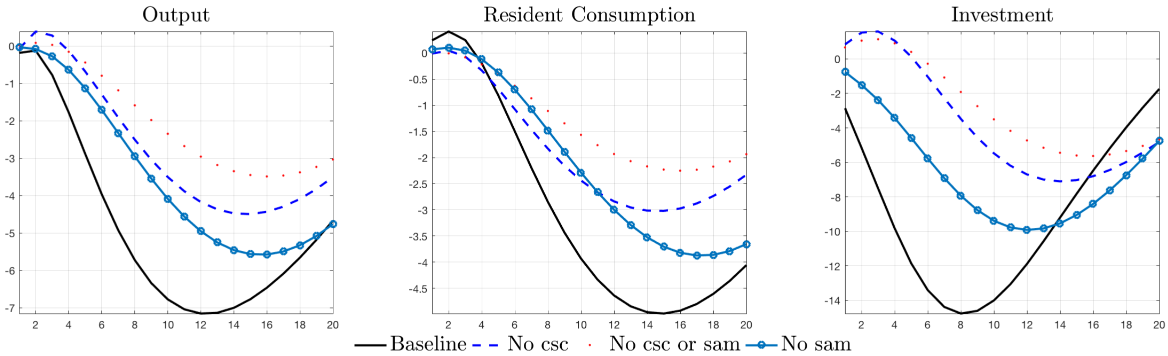

Figure 1.7: Isolating amplification channels

Note: Differences in Impulse Response Functions to a negative risk-premium shock with and without migration. The respective IRFs are in % deviations from steady state. The horizontal axis depicts years. All variables are in aggregate terms.

ification (black line), a model where capital–skill complementarity is shut down[16] (blue dashed line), a model with symmetric search frictions for skilled and unskilled (blue circled line) and a model where both capital skill complementarity and asymmetric frictions are turned off (red dotted line).

When skilled labour is no longer complementary to capital, migration improves the performance of investment in the short run, as firms substitute the scarcer labour for the relatively cheaper capital. This response however is short–lived. With skilled labour being complementary to capital, investment immediately responds to the deteriorating skill composition of the labour force. Importantly, this response is magnified in the presence of search and matching asymmetries for the skilled and unskilled labour. The interplay between the production and the labour market externalities generates a strong amplification due to migration, and leads to a drop in investment which is almost 15% larger compared to the no migration–case.

1.6 Conclusion

This paper investigates the impact of cross-country migration for the business cycle of origin countries, bringing the compositional effects of labour mobility to the forefront of the debate. To do so, I build a small open economy DSGE model with heterogeneous households and three key features: search frictions in the labour

[16] I assume that $\gamma = \nu$ in the no CSC specification.

market, endogenous mobility between countries and capital-skill complementarities in the production function.

I find that the surge in migration outflows from Greece during the Sovereign Debt crisis amplified the recession. The skill composition of emigration flows, which disproportionately reflected the exodus of highly educated workers, played a key role for this result. The "brain drain" effect of migration had a particularly severe impact on capital demand. I find that migration led to a more than 15% drop in investment compared to the no-migration scenario, and that the interplay between the externalities in the production technology and the labour market was an important driver of this result.

This analysis suggests that cross-country mobility is an incomplete mechanism to achieve macroeconomic adjustment. In fact, this paper shows that depending on who leaves migration can significantly exacerbate internal imbalances. An interesting extension would be to investigate the impact of migration on the long-run level of productive capacity in origin countries. If high productivity growth sectors are disproportionately affected by emigration (e.g., because of lower R&D investment or lower intangible capital) then cyclical labour mobility can have a long-lasting impact on economic activity. Relatedly, if migration leads to higher misallocation of labour (e.g., due to lower returns on training) it may result in hysteresis and persistent scarring of the economy.

Acknowledgements I am grateful to my supervisor, Andrea Ferrero, for his insightful feedback, advice and support. I am particularly thankful also to Harris Dellas for his valuable mentorship and support, and to Francesco Zanetti for his very helpful feedback and discussions. This paper has benefited greatly from conversations with Evgenia Vella, Petr Sedlacek, Michael McMahon, Federica Romei, Sergio de Ferra, Martin Ellison and Filippos Petroulakis. It also benefited from the very warm hospitality, presentations and conversations with economists at the Danish National Bank as well as the Federal Reserve Bank of Saint Louis. I would like to thank fellow graduate students and post-docs at the University of Oxford for useful comments and suggestions. I am particularly thankful to Rajssa Mechelli, Alex Haas and Genevieve Nelson for conversations and suggestions. The support of the Economic and Social Research Council, the David Walton Scholarship and the Onassis Foundation are gratefully acknowledged. The views expressed and any remaining errors are my own.

Appendices of chapter 1

Description of appendix to chapter 1

Section 1.A lays out the remaining model equations, while section 1.B contains additional data figures. Section 1.C provides additional experiments and robustness checks and the final Section 1.D outlines a detailed table summarizing the calibration strategy used.

1.A Mathematical appendix

Model equations

Exposition of low-skilled household's decision problem

$$\underbrace{\max}_{c_{l,t},\mu_{l,t}} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left(\log(c_{l,t} - \xi \overline{c}_{l,t-1}) - \Omega_l n^e_{l,t}\right) \text{ , s.t} \tag{1.39}$$

$$c_{l,t} + \frac{\Gamma_l}{2}\left(\frac{\mu_{l,t}\, u_{l,t}}{\mu_{l,t-1}\, u_{l,t-1}} - 1\right)^2 \mu_{l,t}\, u_{l,t} = w_{l,t} n^r_{l,t} + Q_t w^\star_{l,t}\, n^e_{l,t} + \phi_l u_{l,t} + t_{l,t} \tag{1.40}$$

The household takes prices $\{w_{l,t}\ , w^\star_{l,t}\ , Q_t\}$ as well as $t_{l,t}\ , n^r_{l,t}\ , n^e_{l,t}$ as given and solves the utility maximisation problem subject to the budget constraint as well as the law of motion of emigrant and resident labour (1.6 and 1.7). The marginal utility of consumption is defined as

$$\Lambda^c_{l,t} = (c_{l,t} - \xi \overline{c}_{l,t-1})^{-1}\ . \tag{1.41}$$

Under complete domestic markets, the risk-sharing condition (1.11) holds

$$\Lambda^c_{l,t} = \tilde{\Theta} \Lambda^c_{h,t} \tag{1.42}$$

The remaining equilibrium conditions are as follows

$$n^r_{l,t+1} = (1-\rho_l) n^r_{l,t} + f_{l,t}(1-\mu_{l,t}) u_{l,t} \tag{1.43}$$

$$n^e_{l,t+1} = (1-\rho^\star_l) n^e_{l,t} + f^\star_{l,t} \mu_{l,t} u_{l,t} \tag{1.44}$$

$$\Lambda^r_{l,t} = \beta \mathbb{E}_t \Lambda^c_{l,t+1} \left(w_{l,t+1} - \phi_l\right) + (1 - \varrho_l - f_{l,t+1}) \Lambda^r_{l,t+1}) \tag{1.45}$$

$$\begin{aligned} \Lambda^e_{l,t} &= -\beta \Omega_l + \beta \mathbb{E}_t \Lambda^c_{l,t+1} \left(Q_{t+1} w^\star_{l,t+1} - \phi_l\right) \\ &\quad + \beta \mathbb{E}_t (1-\varrho^\star_l) \Lambda^e_{l,t+1} - \beta \mathbb{E}_t f_{l,t+1} \Lambda^r_{l,t+1}\ . \end{aligned} \tag{1.46}$$

$$f^{\star}_{l,t}\,\Lambda^{e}_{l,t} - f_{l,t}\,\Lambda^{r}_{l,t} = \Lambda^{c}_{l,t}\left(\frac{\mathit{\Gamma}_l}{2}\left(\frac{\mu_{l,t}u_{l,t}}{\mu_{l,t-1}u_{l,t-1}} - 1\right)^2 + \mathit{\Gamma}_l\left(\frac{\mu_{l,t}u_{l,t}}{\mu_{l,t-1}u_{l,t-1}} - 1\right)\frac{\mu_{l,t}u_{l,t}}{\mu_{l,t-1}u_{l,t-1}} + \right.$$

$$\left.\beta\mathbb{E}_t\Lambda^{c}_{l,t+1}\mathit{\Gamma}_l\left(\frac{\mu_{l,t+1}u_{l,t+1}}{\mu_{l,t}u_{l,t}} - 1\right)\left(\frac{\mu_{l,t+1}u_{i,t+1}}{\mu_{l,t}u_{l,t}})^2\right)\right., \tag{1.47}$$

$$c^{e}_{l,t}n^{e}_{l,t} = w^{\star}_{l,t}n^{e}_{l,t} - Z_{l,t}n^{e}_{l,t} = (1-\zeta)w^{\star}_{l,t}n^{e}_{l,t}\,. \tag{1.48}$$

$$c_{l,t} = (u_{l,t} + n^{r}_{l,t})c^{r}_{l,t} + Q_t n^{e}_{l,t}c^{e}_{l,t} \tag{1.49}$$

Additional equilibrium equations for high-skilled household

$$\Lambda^{c}_{h,t} = (c_{h,t} - \xi\bar{c}_{h,t-1})^{-1} \tag{1.50}$$

$$1 = \mathbb{E}_t\beta\frac{Q_{t+1}}{Q_t}\frac{\Lambda^{c}_{h,t+1}}{\Lambda^{c}_{h,t}}R^{\star}_{t+1} \tag{1.51}$$

$$T_t = \mathbb{E}_t\beta\frac{\Lambda^{c}_{h,t+1}}{\Lambda^{c}_{h,t}}\left(r^{K}_{t+1} + T_{t+1}(1-\delta)\right) \tag{1.52}$$

$$\frac{1}{T_t} = 1 - \frac{\Xi}{2}(\frac{i_t}{i_{t-1}} - 1)^2 - \Xi(\frac{i_t}{i_{t-1}} - 1)^2\frac{i_t}{i_{t-1}} + \mathbb{E}_t\beta\frac{\Lambda^{c}_{h,t+1}}{\Lambda^{c}_{h,t}}\frac{T_{t+1}}{T_t}\Xi\left(\frac{i_{t+1}}{i_t} - 1\right)\left(\frac{i_{t+1}}{i_t}\right)^2 \tag{1.53}$$

where T_t denotes the shadow value of capital.

1.B Data figures

The following figure depicts the share of skilled immigration flows from European periphery to Germany. Skill groups are based on declared occupation. Specifically, following the ISCO occupations classification, I classify survey respondents as high–skilled if their occupation falls into groups 1–3 (Managers, Professionals, Technicians and associate professionals). The remaining are classified as low–skilled. As is evident from this plot, the shift in the skill content of migration is robust to different measures of skill.

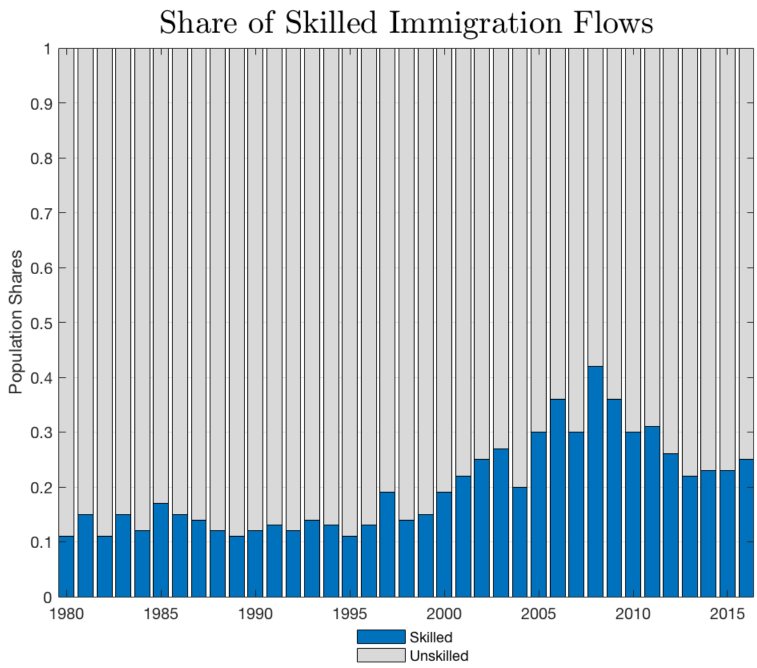

Figure 1.B.1: Share of skilled immigration flows

Note: Immigration flows from periphery (Ireland, Greece, Spain, Italy and Portugal) to Germany. Skill classification is via occupations. The sample is controlled for working age at year of entry (years 25-64 to account for education-related migration).
Source: German Microcensus.

Figures 1.B.2 and 1.B.3 depict net emigration flows and the evolution of the skill share of the domestic working age population for European periphery countries. Emigration flows turned from being negative prior to the Sovereign Debt crisis to positive in line with the change in gross emigration flows. Turning to the evolution of the skill shares, it is interesting to note that despite their rapid increase over the past 25 years, they remained relatively stable during the crisis, when skilled-emigration increased.

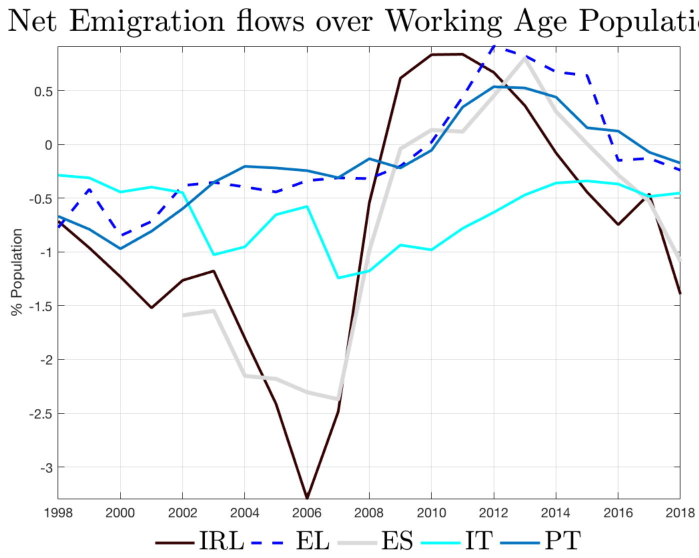

Figure 1.B.2: Net emigration flows over working age population

Note: Net emigration flows from European periphery (Ireland, Greece, Spain, Italy and Portugal) as a % of working age population (years 15-64).
Source: Eurostat.

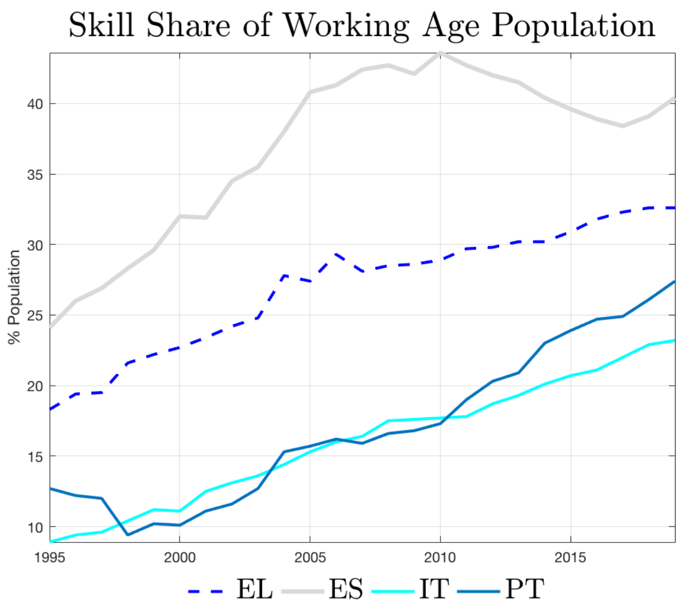

Figure 1.B.3: Skill share of working age population

Note: Skill share as a % of working age population (years 15-64).
Source: Eurostat.

1.C Additional results

Additional experiment results

Figure 1.C.4 displays responses of additional labour market variables to a negative risk-premium shock. Note that here unemployment rates refer to a narrower measure that excludes those who search at Foreign.

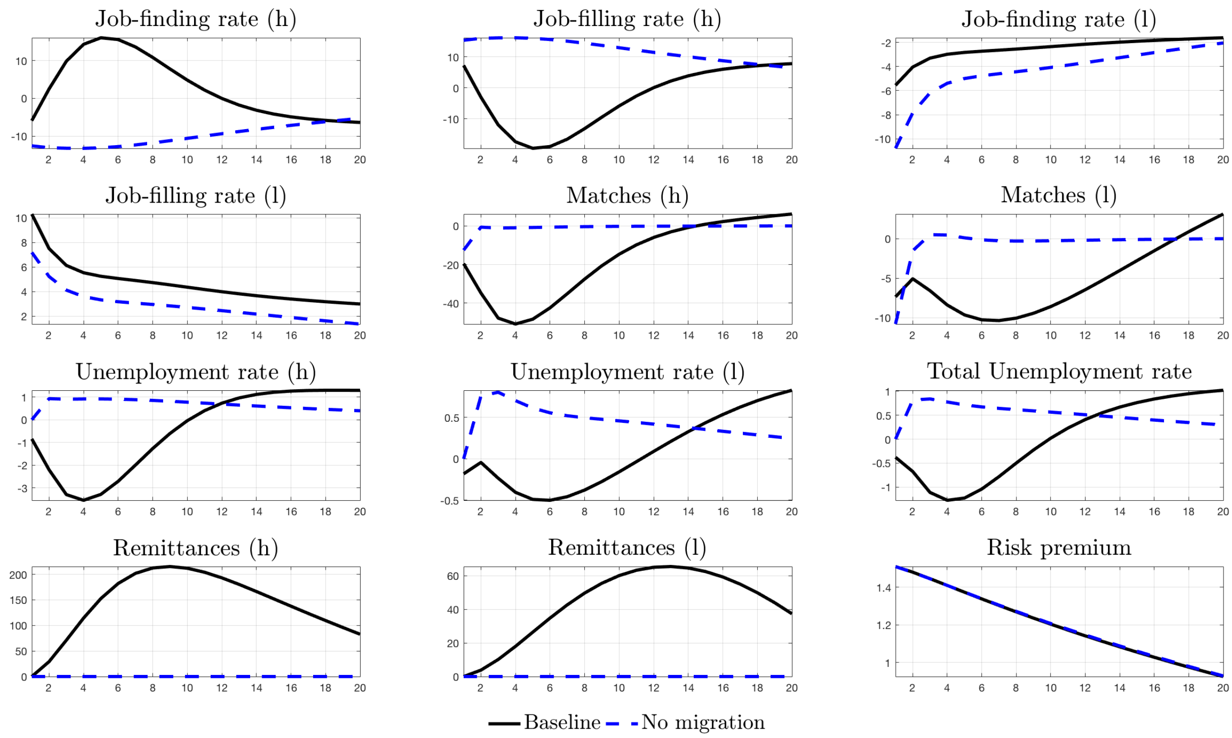

Figure 1.C.4: Labour market impacts to a risk premium shock

Note: Impulse Response Functions to a negative risk-premium shock. IRFs are in terms of % deviations from the steady state with the exception of the unemployment rates. The parenthesis terms refer to skilled households (h) and unskilled households (l). Horizontal line depicts years.

Figure 1.C.5 compared the responses of GDP and main components under the migration of only skilled labour, under the migration of only unskilled labour and under the baseline scenario (which features migration of both skill types). In the data series, consumption refers to total final consumption expenditure of households, investment to gross fixed capital formation and trade balance to net exports of goods. All variables are in aggregate terms.

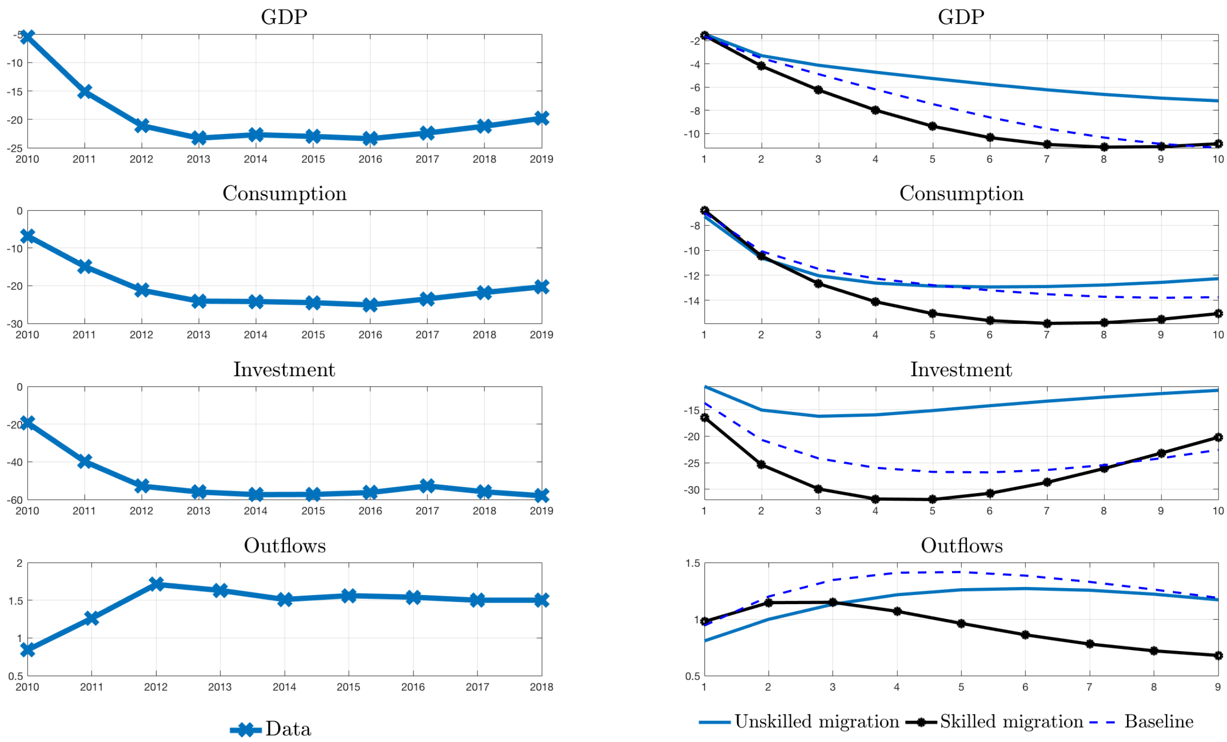

Figure 1.C.5: Data vs model dynamics (b)

Note: Impulse Response Functions to a negative risk-premium shock. The data series are in % deviations from their 2009 values apart from outflows. Measurements are in chain linked volumes (2010). Model responses are in % deviations from steady state apart from outflows. Outflows are in % of total working age population.
Source: ELSTAT.

Sensitivity analysis

Figure 1.C.6 displays robustness checks of our analysis with respect to different specifications of the CSC production function. As is evident from the figures below, our results remain robust for several combinations of the parameters controlling the degree of CSC. The choice of parameter combinations is guided by the empirical findings of Krusell et al. (2000), using US data, Lindquist (2005), based on Swedish data, and Batista (2007), based on Portuguese data.

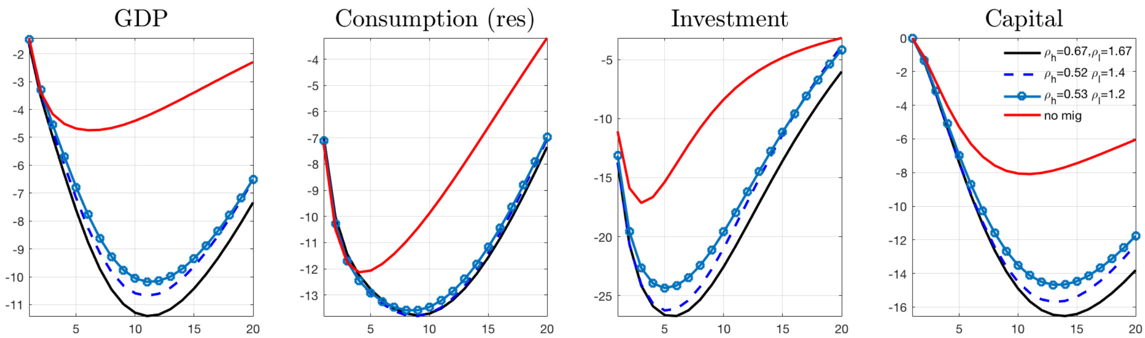

Figure 1.C.6: Sensitivity to CSC parameters

Note: Impulse Response Functions to a negative risk-premium shock under different specifications of the CSC production function. IRFs are in terms of % deviations from the steady state.

1.D Calibration strategy

TABLE 1.D.1. **CALIBRATION STRATEGY**

Parameter	Description	Value	Rationale
β	subjective discount factor	0.96	4% annual real interest rate
ξ	habits	0.6	Papageorgiou (2014)
θ	$X_d - X_f$ elasticity of substitution	1.65	Chodorow-Reich et al. (2019)
δ	depreciation rate	0.08	Chodorow-Reich et al. (2019)
ω	home bias	0.75	Chodorow-Reich et al. (2019)
$\rho_{k,l}$	$K - N_l$ elasticity of substitution	1.67	Krusell et al. (2000)
$\rho_{k,h}$	$K - N_h$ elasticity of substitution	0.67	Krusell et al. (2000)
s_s	skilled bundle share	0.47	skilled share–EUKLEMS
s_k	capital share	0.89	capital share–Papageorgiou (2014)
M_h	mass high-skilled	0.31	Eurostat
M_l	mass low-skilled	0.69	Eurostat
$\Omega_{h,l}$	disutility of moving	1.24, 0.22	8% emigrant stock, 35% skilled
$\Gamma_{h,l}$	pecuniary moving cost	0.98, 6.5	7% cumulative outflows, 65% skilled
χ_h	matching efficiency	0.86	7% unemployment rate of skilled
χ_l	Matching efficiency	0.61	12% unemployment rate of unskilled
$\rho_{h,l}$	separation rate	0.08	Hobijn and Sahin (2009)
κ_h	vacancy posting cost	0.1	job-filling rate 0.7 skilled
κ_l	vacancy posting cost	0.43	job-filling rate 0.6 low-skilled
$\epsilon_h\ \epsilon_l$	elasticity of matches to workers	0.6,0.4	Pissarides and Petrongolo (2001)
$\psi_h\ \psi_l$	bargaining power of workers	0.6,0.4	Hosios (1990)
γ_w	real wage rigidities	0.65	Papageorgiou (2014)
$w_h^\star$	foreign wage premia	$w_h^\star/w_h = 1.45$	EUKLEMS
$w_l^\star$	foreign wage premia	$w_l^\star/w_l = 1.05$	EUKLEMS
Ψ	Debt-elastic rate	0.001	Schmitt-Grohe and Uribe (2003)
Ξ	Investment adj. cost	0.9	Papageorgiou (2014)
$\omega^\star$	Foreign home bias	0.24	$y^{star} = 1$ normalisation
g	Government expenditure	0.15	$\frac{G^{ss}}{gdp^{ss}} = 0.18$, ELSTAT
ζ	Remittances share	0.47	$\frac{Rem}{gdp} = 0.3\%$, World Bank
ρ^{rp}	Risk premium shock persistence	0.98	Literature
σ^{rp}	Risk premium shock std	0.015	Literature

CHAPTER 2

Macroeconomic uncertainty: the role of endogenous job destruction

Abstract Uncertainty has once again become of pivotal importance for academics and policymakers alike. This paper focuses on the role of labour market frictions for the propagation of uncertainty shocks and analyses the significance of the job destruction channel. To address this question, I build a DSGE model with search frictions in the labour market, price stickiness in the goods market and time-varying stochastic volatility, which I calibrate to match salient features of the US economy. I find that endogenous job separations can significantly amplify the reaction of the economy to uncertainty shocks. In a series of experiments with different monetary policy rules, I also find that the introduction of endogenous match separations can challenge the widely-held perception that uncertainty shocks behave like negative aggregate demand shocks, as the behaviour of inflation hinges on the Taylor rule specification.

2.1 Introduction

In the years following the global financial crisis of 2008, macroeconomic uncertainty has become a focal point of debate for academics, policy makers and market participants alike. COVID-19 and the subsequent crisis, which is promising to be the most severe crisis in our generation, has triggered an unprecedented increase in uncertainty and has highlighted the importance of understanding the mechanisms through which uncertainty affects the real economy. This paper explores the critical role that the labour market plays in the propagation of uncertainty shocks and focuses on the importance of the job-destruction channel.

The paper contributes to the literature by investigating the role of labour market frictions, and specifically the role of endogenous job separations on the business cycle effects of uncertainty. It also studies how different labour market structural characteristics affect the resilience of key macroeconomic variables to uncertainty, focusing on the role of firing costs, a topic that is unexplored to the best of my knowledge.

To address these questions, I build a Dynamic Stochastic General Equilibrium (DSGE) model. The model features search-and-matching frictions and real wage rigidities in the labour market as well as nominal rigidities in the goods market and allows for endogenous job separations. I then perform a number of experiments in order to explore the interactions between different labour market adjustment margins and aggregate uncertainty. I focus specifically on how changes in firing costs affect the transmission of uncertainty. Uncertainty shocks are specified as shocks to the time-varying stochastic volatility of the technology process following Fernandez-Villaverde et al. (2011), and subsequent literature. I calibrate the benchmark economy to US data in order to facilitate direct comparisons with previous studies on uncertainty and I solve the model using third-order perturbation techniques and pruning.

An important finding of this paper is that the presence of endogenous job separations amplifies the negative impact of uncertainty shocks relative to a case with exogenous job destruction, making unemployment, consumption and output more responsive to uncertainty. The key mechanism at play is the precautionary savings motive of households. In anticipation of future adverse shocks due to heightened uncertainty, prudent households have an incentive to reduce current consumption and increase savings in order to build a buffer wealth stock. The drop in aggregate demand leads to a lower value of job matches and induces firms to increase job separations. The resulting increase in unemployment amplifies the precautionary motive of households and the negative impact of uncertainty shocks.

To assess the quantitative importance of the job destruction channel for uncertainty and highlight the role of firing costs, I consider a benchmark economy which is calibrated to US data. In the model, firing costs are equivalent to a tax that the firm pays proportionally to the mass of dismissed workers. I then compare the dynamic responses of the variables in the benchmark economy, in which firing costs are set to zero, to a situation where firing costs increase to levels observed in the Euro Area, as well as intermediate cases. I find that an increase in firing costs slightly improves the resilience of the economy to uncertainty shocks as it mitigates the strength of the job destruction channel.[1] This holds despite the fact that, under more costly firing, vacancies respond more negatively to uncertainty shocks, thus contributing to higher unemployment via lower job-finding rates. The opposite impact of changes in firing costs on the job destruction and job creation channels allows me to assess the relative importance of the two for aggregate fluctuations in response to uncertainty shocks. For parameterizations of the model that enable it to fit the empirical behaviour of vacancies, I find that the job-destruction channel is marginally stronger.

Next, I explore how different monetary policy rules affect the propagation of uncertainty. I show that the introduction of endogenous job separations challenges the key finding of Leduc and Liu (2016) that uncertainty shocks behave like aggregate demand shocks. In line with recent evidence by Fasani and Rossi (2018), I find that whether uncertainty shocks bear resemblance to demand or supply shocks hinges on the specification of the monetary policy rule. For empirically plausible specifications of the Taylor rule that feature interest-rate smoothing, I find that the inflationary pressures due to the precautionary pricing behaviour of firms largely

[1] This result is in line with the empirical findings of Messina and Vallanti (2007), who show that in countries with stricter firing restrictions and employment protection regulation, job destruction is less responsive to shocks.

offset the deflationary pressures due to lower aggregate demand, resulting in a broadly unchanged inflation in response to uncertainty shocks.[2]

The rest of this paper is organized in the following way. Section 2.2 reviews related literature. Section 2.3 presents the model and sections 2.4 and 2.5 analyse the calibration and computational methods used. Section 2.6 summarizes the economic intuition behind the model. Section 2.7 presents and interprets the results and section 2.8 concludes.

2.2 Related literature

This paper is related to two strands of literature. Firstly, it builds on the literature that studies uncertainty shocks and their implications for the aggregate fluctuations of key macroeconomic variables. Secondly, it contributes to the literature that investigates the role of labour market frictions frictions in business cycle models.

Starting with the seminal work of Bloom (2009), uncertainty shocks and their importance as a driving force of the business cycle have become a rapidly growing research field. Bloom (2009) argues that, in a partial-equilibrium framework, firm-level uncertainty can account for deep recessions as it affects the hiring and investment decisions of the firms. The key transmission mechanism explored is the real option channel. Under non-convex investment adjustment costs, uncertainty about the future state of the economy increases the value of the firms' real option to wait-and-see. As a result, the firms' inaction region expands leading firms to postpone hiring and investment with severe repercussions for real activity. In subsequent work by Bloom et al. (2018), the authors extend this analysis to a general equilibrium framework and confirm the importance of uncertainty shocks in driving recessions. They also find that uncertainty can hamper the process of reallocation of resources from low to high productivity firms, with negative effects on productivity growth.

Other authors have focused on different transmission mechanisms of uncertainty. Influential contributions include Arellano et al. (2019), who investigate the

[2] To facilitate comparison with Leduc and Liu (2016), I closely follow their calibration strategy including their specification of the Taylor rule. I find that their results on the behaviour of inflation are not robust to different monetary policy rules. This finding is complementary to the work of Fasani and Rossi (2018) who examine a similar question but in a model with exogenous job separations.

importance of financial frictions as an amplification mechanism for the effects of firm-level uncertainty, as well as Christiano et al. (2014), who embed a financial accelerator à la Bernanke-Gertler-Gilchrist in a DSGE model and study the effects of risk shocks. Schaal (2017) explores the interactions between labour market frictions and idiosyncratic uncertainty in a framework that features directed search, and shows that the presence of time-varying volatility at the firm level can help improve the fit of business cycle models with respect to labour market variables.[3]

Contrary to the papers mentioned above, which study the effects of idiosyncratic (microeconomic) uncertainty, this chapter focuses on aggregate (macroeconomic) uncertainty. In this respect, this chapter is closely related to Basu and Bundick (2017), Fernandez-Villaverde et al. (2011) and Born and Pfeifer (2014). In contrast with these papers however, I embed search and matching frictions in my framework and focus on the interactions between labour market institutions and uncertainty.

Finally, this paper is closely linked to the work of Leduc and Liu (2016) who were among the first to stress the importance of frictional labour markets for the transmission of aggregate uncertainty. The authors find that uncertainty shocks behave like negative aggregate demand shocks, raising unemployment and decreasing inflation. My paper builds on their model and expands their work by introducing endogenous job separations and exploring the implications of different labour market structures for the propagation of uncertainty shocks.

This paper also contributes to the literature that studies the role of labour market frictions and institutional arrangements for business cycle dynamics. It is closely related to the work of Zanetti (2011), which explores the influence of labour market structural characteristics on business cycle fluctuations through the lens of a closed economy NK-DSGE model. It is also linked to the work of Thomas and Zanetti (2009) and Campolmi and Faia (2011) who focus on the the role of labour

[3]It is worth noting that another vein of literature takes a more critical stance regarding the significance of uncertainty shocks as drivers of business cycles. Bachmann and Bayer (2013) study aggregate uncertainty in a heterogeneous-firm DSGE model with capital-adjustment costs which they estimate using German firm-level data. The authors argue that the wait-and-see effects of uncertainty are quantitatively small and cannot explain the unconditional business cycle dynamics. In a similar spirit, Backus et al. (2014) construct a business cycle model with recursive preferences and find that risk shocks cannot account for the magnitude and persistence of the Great Recession in the US.

market institutions and endogenous job separations for price stability in the context of currency unions, as well as Cacciatore and Fiori (2016) who explore the impact of market structural reforms in an RBC model with endogenous producer entry and frictional labour markets.

My paper differs from the aforementioned papers in that I examine the role of labour market characteristics in the context of uncertainty shocks, rather than the standard business cycle shocks. Because I incorporate uncertainty in the model, the computational methods employed in this paper also differ as the study of uncertainty shocks requires solving the system via third-order perturbation techniques.

2.3 Model

I develop a closed economy DSGE model which features search and matching frictions in the labour market, as well as nominal rigidities in the goods market. The model formulation builds on Leduc and Liu (2016) which studies the impact of uncertainty shocks in a framework with frictional labour markets. I enrich this framework by endogenizing job separations, similarly to Thomas and Zanetti (2009) and Cacciatore and Fiori (2016).

The economy is populated by a continuum of infinitely-lived households with identical preferences. Following Andolfatto (1996), Merz (1995) and subsequent literature, I assume perfect risk-sharing within households such that all members consume the same amount regardless of their employment status. This assumption allows me to abstract from heterogeneity and distributional considerations and to follow a representative-household analysis. The members of the household enjoy utility from consumption, they invest in a risk-free bond and either supply labour and earn labour income or receive unemployment benefits.

Production occurs in a layered fashion: perfectly competitive intermediate good firms employ labour, face search and matching frictions and produce a homogeneous good, which is used as input by monopolistically competitive wholesale firms. Wholesale producers face nominal price rigidities and produce differentiated goods which retailers combine into the final consumption good using a constant elasticity of substitution production technology. Monetary policy follows a Taylor-type feedback rule and fiscal policy follows a budget-balancing rule.

2.3.1 Households

The economy is populated by a continuum of identical households represented by the unit interval $[0, 1]$. The representative household is characterised by the following utility function

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \frac{(C_t - hC_{t-1})^{1-\gamma}}{1-\gamma} \ , \tag{2.1}$$

where $\mathbb{E}_t$ is the expectation operator conditional on the household's information at time t, $\beta \in (0, 1)$ is the subjective discount factor, C_t is the final consumption good, $\gamma > 0$ is the relative risk aversion coefficient and the inverse of the elasticity of intertemporal substitution and h controls for habit formation.

Employed household members receive an average real wage, $\tilde{w}_t$, while unemployed members receive an unemployment benefit, ϕ, also in real terms. Households invest in a one-period nominal risk-free bond B_t that pays gross nominal interest rate R_t, they pay lump-sum taxes T_t and receive dividends from firm ownership D_t. The flow budget constraint is given by

$$P_t C_t + B_t = R_{t-1} B_{t-1} + P_t \tilde{w}_t N_t + P_t \phi (1 - N_t) + T_t + D_t \ , \tag{2.2}$$

where N_t denotes the fraction of household members that are employed at time t and P_t is the price index associated with the final consumption good C_t. In each period, the representative household solves an optimization problem by choosing how many units of the final consumption good C_t to consume and how many units to save through B_t. The optimality condition of the household is described by the Euler Equation as follows

$$1 = \mathbb{E}_t \beta \left\{ \frac{\Lambda_{t+1}}{\Lambda_t} \right\} \frac{R_t}{\pi_{t+1}} \ , \tag{2.3}$$

where the gross inflation rate π_{t+1} is defined as $\pi_{t+1} \equiv \frac{P_{t+1}}{P_t}$. Λ_t denotes the marginal utility of consumption and is equal to $\Lambda_t = (C_t - hC_{t-1})^{-\gamma} - \mathbb{E}\beta h (C_{t+1} - hC_t)^{-\gamma}$. The Euler equation describes the optimal intertemporal consumption-saving decision of the household and captures the fact that along the optimal consumption path an agent should be indifferent between consuming an extra unit of the final good today or saving that unit for consumption in the next period.

2.3.2 Labour market

The labour market block features search and matching frictions à la Mortensen and Pissarides (1994). In this framework, the matching process between firms and workers is costly, resulting in positive involuntary unemployment in equilibrium, contrary to a frictionless labour market framework. Firms post vacancies subject to paying a fixed cost and destroy unprofitable job matches subject to paying firing costs, while unemployed workers search for jobs. The technology that governs their matching process is described by a constant returns to scale matching function m_t

$$m_t = \mu u_t^{\alpha} v_t^{1-\alpha} \ , \tag{2.4}$$

where parameter μ captures the matching efficiency, α is the elasticity of matches with respect to the unemployed workers, m_t is the number of matches, v_t denotes vacancy postings and u_t denotes searching unemployed workers. Additional equations that characterize the labour market are the job-filling rate,

$$q_t^v \equiv \frac{m_t}{v_t} \ , \tag{2.5}$$

and the job-finding rate,

$$q_t^u \equiv \frac{m_t}{u_t} \ , \tag{2.6}$$

where θ denotes labour market tightness and is defined as $\theta_t \equiv \frac{v_t}{u_t}$.

As can be seen from these equations, the job-filling rate is decreasing in the labour market tightness θ while the job-finding rate is increasing in θ. At the beginning of each period, a fraction λ^x of job matches is exogenously destroyed. Aggregate and idiosyncratic productivity shocks are subsequently realized and firms endogenously terminate a fraction λ_t^n of job matches for which the continuation value falls below the firing costs. Following Sala et al. (2008) and Bandeira et al. (2019) among others, I assume that new matches become productive with a lag. The law of motion of the firm's workforce is given by

$$N_t = (1 - \lambda^x)(1 - \lambda_t^n)\left(N_{t-1} + q_{t-1}^v \, v_{t-1}\right) \ . \tag{2.7}$$

Population is normalised to 1. Under the additional full participation assumption, the unemployment rate is given by

$$U_t = 1 - N_t \ . \tag{2.8}$$

2.3.3 Firms

Following Blanchard and Gali (2010), I disaggregate production into three stages in order to abstract from interactions between search frictions and price rigidities at the firm level. In the first stage, perfectly competitive firms use labour as a production factor and create a homogeneous intermediate good. In the second stage, monopolistically competitive firms produce differentiated goods using a brand-naming technology, while in the final stage of production a representative retailer combines differentiated goods into a homogeneous final consumption good using a CES technology.

Intermediate good firms

Within each intermediate good firm there is a unit mass of jobs. Each job is executed by one worker and is characterised by a job-specific productivity z_t. As commonly assumed in the literature, z_t is an i.i.d. draw from a time-invariant distribution with cumulative distribution function $G(z)$, density $g(z)$ and support on $[z_{min}, \infty)$. When the idiosyncratic productivity of workers falls below a cutoff level z_t^c, the job match becomes unprofitable and a fraction $G(z_t^c)$ of workers is endogenously separated (with the mass of endogenously destroyed matches also being equal to the endogenous separation rate λ_t^n).

The production technology for a representative firm at the first stage of production is given by

$$X_t = A_t \, N_t \int_{z_t^c}^{\infty} \frac{z g(z)}{1 - G(z_t^c)} d(z) \, , \tag{2.9}$$

where X_t is the intermediate good produced and A_t captures the state of technology. The exogenous process of technology is analysed in more detail later.

Firms choose how many vacancies to post, how many workers to employ and the productivity threshold z_t^c in order to maximize their profit function

$$\max_{\{v_t, N_t, z_t^c\}_{t=0}^{\infty}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left(\frac{\Lambda_{t+s}}{\Lambda_t} \right) \left(p_s^w X_s - \tilde{w}_s N_s - \kappa v_s - F \, G(z_s^c) \, (1 - \lambda^x)(N_{s-1} + q_{s-1}^v \, v_{s-1}) \right) \, , \tag{2.10}$$

where p_t^w is the price of the input good relative to the price index P_t, κ is the real cost of posting a vacancy in terms of the final consumption good and F denotes the firing costs in real terms. I abstract from severance payments as such transfers from firms to workers would not change the joint match surplus. Instead, I assume that firing costs are a pure waste (we can think of them as wasted resources due to legal and administrative costs). The average wage $\tilde{w}_s$ is defined as $\tilde{w_s} \equiv \int_{z_t^c} \frac{w(z)g(z)}{1-G(z_t^c)} d(z)$. Firms maximize the present discounted value of their real profits subject to the production technology constraint (2.9) and the law of motion of employment (2.7).

Solving this problem and combining the first-order conditions for N_t and v_t, yields the following optimality condition

$$\frac{\kappa}{q_t^v} = (1-\lambda^x)\mathbb{E}_t \, \beta(\frac{\Lambda_{t+1}}{\Lambda_t}) \left((1 - G(z_{t+1}^c))(p_{t+1}^w \frac{X_{t+1}}{N_{t+1}} - \tilde{w}_{t+1} + \frac{\kappa}{q_{t+1}^v}) - G(z_{t+1}^c) F \right) . \tag{2.11}$$

The LHS of this Job Creation condition expresses the marginal cost of posting a vacancy which is equal to the real cost, κ, times the expected duration that the vacancy remains unfilled, $\frac{1}{q_t^v}$. The RHS captures the marginal benefit of posting a vacancy which can be decomposed into two terms. The first term captures the expected profit flow of a job match (i.e. the average revenue created by an additional worker minus average real wages) and the expected continuation value of the match conditional on survival with probability $(1 - G(z_{t+1}^c))$. The second term captures the expected separation costs if the match is endogenously separated which occurs with probability $(1 - \lambda^x)G(z_{t+1}^c)$. The Job Creation condition equates the expected costs and expected benefits of the match.

The first-order condition on z_t^c yields the following optimality condition

$$p_t^w A_t z_t^c - w(z_t^c) + \frac{\kappa}{q_t^v} = -F \; . \tag{2.12}$$

Eq. (2.12) equalizes the value of a match with cutoff productivity z_t^c to zero as the firm is indifferent between keeping the marginal worker, in which case it gains the profit flow and continuation value of the job match, and firing her, in which case it incurs firing costs F.

Wage schedule

In the current framework, workers and firms have monopoly power due to the existence of real search costs which, apart from vacancy posting costs, include foregone real wages and production. As a result, there is an economic rent associated with each job match to be split between workers and firms according to some wage rule.

Following Campolmi and Faia (2011) and Thomas and Zanetti (2009) among others, I assume that wages are determined as the solution to a Nash Bargaining problem which shares the joint surplus of a job match based on the workers' bargaining power parameter $b \in (0,1)$. Bargaining occurs on a per-period basis between the representative firm and the individual workers.

The firm's surplus when matched with a worker of productivity z_t is denoted as $\mathcal{S}_t^F$ and is composed of two terms. The first one is the value of the job match to the firm which is given by the following Bellman equation

$$\mathcal{J}_t^F(z) = p_t^w A_t z_t - w(z_t) + (1-\lambda^x)\mathbb{E}_t\beta\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left[(1-G(z_{t+1}^c))\tilde{\mathcal{J}}_{t+1}^F - G(z_{t+1}^c)F\right] , \tag{2.13}$$

where $\tilde{\mathcal{J}_{t+1}^F}$ is the expected firm value of a match and is equal to $\tilde{\mathcal{J}}_t^F \equiv \int_{z_t^c} \frac{\mathcal{J}_t^F(z)g(z)}{1-G(z_t^c)}d(z)$. Eq. (2.13) states that the match value is equal to the profit flow generated, plus the continuation value of the job match. The second term of the firm's surplus corresponds to savings from firing costs F. Combining both yields the following expression

$$\mathcal{S}_t^F(z) = \mathcal{J}_t^F(z) + F . \tag{2.14}$$

The match surplus for a worker of productivity z_t is given by

$$\mathcal{S}_t^W(z) = w_t(z) - \mathcal{U}_t + (1-\lambda^x)\beta\mathbb{E}_t\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left\{(1-G(z_{t+1}^c))\tilde{\mathcal{S}}_{t+1}^W(z)\right\} , \tag{2.15}$$

where the average worker's match surplus is defined as $\tilde{\mathcal{S}}_t^W(z) \equiv \int_{z_t^c} \frac{\mathcal{S}_t^W(z)g(z)}{1-G(z_t^c)}d(z)$.

The term $\mathcal{U}_t$ characterises the outside option of the worker and is given by

$$\mathcal{U}_t = \phi + h^p + (1-\lambda^x)\beta\mathbb{E}_t\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left[\int_0^1 \frac{q_t^u v_{j,t}}{V_t}(1-G(z_{j,t+1}^c))\tilde{\mathcal{S}}_{j,t+1}^W(z)dj\right] . \tag{2.16}$$

The unemployed worker gains an unemployment benefit ϕ, in units of the final consumption good, and home production h^p. Additionally, she gains the expected discounted value of search for other job matches. With probability $\frac{q_t^u v_{j,t}}{V_t}$ a worker is matched with job j at time t and conditional on the match surviving in the next period, with probability $(1-G(z_{j,t+1}^c))$, she receives match surplus $\mathcal{S}_{j,t+1}^W(z)$. Note

that the outside option is the same for all workers as I assume that the unemployment benefit and the home production do not vary with z_t, and that next period's productivity does not depend on current levels.
Let the total match surplus be $\mathcal{S}_t$

$$\mathcal{S}_t(z) = (\mathcal{J}_t^F(z) + F) + \mathcal{S}_t^W(z) \ . \tag{2.17}$$

Then under Nash bargaining

$$\mathcal{J}_t^F(z) + F = (1-b)\,\mathcal{S}_t(z) \tag{2.18}$$

$$\mathcal{S}_t^W(z) = b\,\mathcal{S}_t(z) \ , \tag{2.19}$$

which imply the following expression for the real wage[4]

$$w_t(z) = (1-b)(\phi + h^p) + b\left(p_t^w A_t z + \kappa\theta + \left[1 - (1-q_t^u)(1-\lambda^x)\beta\mathbb{E}_t\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\right]F\right) \ . \tag{2.20}$$

The first term corresponds to the reservation wage for workers which is equal to the unemployment benefit and home production. The second term captures the job match surplus for the firm and is equal to the productive value of the match and the expected gains for not having to incur a vacancy posting cost next period, accounting for firing costs. Specifically, the firm gains from saving on firing costs today but factors in the expected firing costs in the next period. As b increases, the worker extracts a bigger share of the matching rents. In the limiting case when $b \to 1$, the worker extracts the entire surplus of the firm, while in the case when $b \to 0$, she only receives her reservation wage.

Retail firms

A representative firm combines a continuum of differentiated goods indexed by $j \in [0,1]$, using a constant elasticity of substitution technology and produces a homogeneous final good Y_t. The CES production technology is given by

$$Y_t = \left[\int_0^1 y_t(j)^{\frac{\eta-1}{\eta}} dj\right]^{\frac{\eta}{\eta-1}} \ , \tag{2.21}$$

[4]For a detailed derivation of the Nash Bargaining wage see the Appendix 2.

where $\eta > 1$ is the elasticity of substitution between differentiated goods. The representative firm chooses the optimal amount $y(j)$ of each type j of input goods in order to maximize the profit function

$$\max_{y_t(j)} P_t Y_t - \int_0^1 P_t(j) y_t(j) dj \ , \tag{2.22}$$

subject to the production technology (2.21). The retailer's optimality condition is

$$y_t^d(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\eta} Y_t \ . \tag{2.23}$$

The demand for the differentiated good j is inversely proportional to its relative price and depends on the elasticity of substitution η. The associated price index P_t is derived using the zero profit condition and is equal to

$$P_t = \left[\int_0^1 P_t(j)^{1-\eta} dj\right]^{\frac{1}{1-\eta}} \ . \tag{2.24}$$

Wholesale firms

In the second stage of production, there is a continuum of wholesale firms represented by the unit interval. Each firm produces a differentiated product. Firms behave as price takers in the input market and as price setters in the output market. They face nominal rigidities due to quadratic costs of price adjustment à la Rotemberg. Their production function is given by

$$y_t(j) = x_t(j) \ , \tag{2.25}$$

where $x_t(j)$ is the amount of input good used by firm j and $y_t(j)$ is the amount produced by j. Their profit function, expressed in real terms, is given by

$$\max_{P_t(j)} \mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \left(\frac{\Lambda_{t+i}}{\Lambda_t}\right) \left(\left[\left(\frac{P_{t+i}(j)}{P_{t+i}}\right) - p_{t+i}^w \right] y_{t+i}(j) - \frac{\Omega}{2} \left(\frac{P_{t+i}(j)}{\pi \, P_{t+i-1}(j)} - 1\right)^2 Y_{t+i} \right) \ , \tag{2.26}$$

where p_t^w is the real marginal cost, which is equal to the relative price of the input good, and π is the steady-state gross inflation rate. The final term inside the parenthesis denotes the price adjustment costs which are scaled by the parameter Ω, the degree of nominal price stickiness, and are measured in units of the final good.

They are increasing in the size of the price changes and the size of total economic activity, and can be rationalised as capturing the negative impact of price changes on the firm-customer relationships (Rotemberg, 1982).

Wholesale firms maximize their profits subject to the technology constraint and the optimal demand schedule (2.22). Taking into account that $P_t(j) = P_t$ for all j under the symmetric equilibrium, and after the algebraic manipulations described in Appendix 2, the firms' optimal price-setting decision yields

$$p_t^w = \frac{\eta - 1}{\eta} + \frac{\Omega}{\eta}\left\{\left(\frac{\pi_t}{\pi} - 1\right)\frac{\pi_t}{\pi} - \beta \mathbb{E}_t(\frac{\Lambda_{t+i}}{\Lambda_t})\frac{Y_{t+1}}{Y_t}\left(\frac{\pi_{t+1}}{\pi} - 1\right)\frac{\pi_{t+1}}{\pi}\right\} . \tag{2.27}$$

In a frictionless environment (i.e., for $\Omega = 0$), the optimality condition of the firms equates the real marginal cost to the inverse of the steady-state markup which depends on the elasticity of substitution η.

2.3.4 Monetary and fiscal policy

Monetary policy

I assume that the central bank sets interest rates according to the following Taylor-type rule

$$R_t = \left(R^* \left(\frac{\pi_t}{\bar{\pi}}\right)^{\varphi_\pi}\left(\frac{Y_t}{\bar{Y}}\right)^{\varphi_y}\right)^{1-\varphi_i} R_{t-1}^{\varphi_i} , \tag{2.28}$$

where R_t is the nominal interest rate and R^* is its steady-state value. The monetary authority responds to changes in inflation and output from their targets values $\bar{\pi}$ and $\bar{Y}$ respectively, with the response coefficients φ_π and φ_y controlling how aggressively the central bank reacts to deviations. I assume that the central bank has a preference for smoothing policy, with parameter φ_i controlling the degree of inertia in the Taylor Rule.

Fiscal policy

I assume that government spending is restricted to transfers in the form of unemployment benefits which are entirely financed through lump-sum taxes. Budget balancing holds in every period

$$T_t = \phi(1 - N_t) . \tag{2.29}$$

2.3.5 Market clearing conditions

Labour markets do not clear due to search frictions which result in positive involuntary equilibrium unemployment. In equilibrium markets for intermediate, wholesale and final consumption goods clear. These market-clearing conditions require that

$$Y_t = A_t \tilde{z}_t N_t \tag{2.30}$$

$$Y_t = C_t + \kappa\, v_t + F_t + \frac{\Omega}{2}\left(\frac{\pi_t}{\pi} - 1\right)^2 Y_t\ , \tag{2.31}$$

where total firing costs F_t are expressed as $F_t \equiv F \frac{G(z_t^c)N_t}{1-G(z_t^c)}$.

Furthermore, the asset market clearing implies that net supply of the nominal risk-free bond is zero in equilibrium

$$B_t = B_{t+1} = 0\ . \tag{2.32}$$

2.3.6 Exogenous processes

The specification of the exogenous processes closely follows Leduc and Liu (2016) and Fernandez-Villaverde et al. (2011). I assume that A_t varies exogenously according to the following AR(1) process

$$\ln A_t = (1-\rho_a)\ln A + \rho_a \ln A_{t-1} + \sigma_t \epsilon_t\ , \tag{2.33}$$

where $\rho_a \in (0,1)$ captures the persistence of the technology shock. The term ϵ_t is a random variable following an i.i.d. standard normal distribution and is the innovation to the stochastic technology process (also called first-moment shock). The term σ_t is the standard deviation of the innovation to the technology process. The distinctive feature of this type of models is that the standard deviation of ϵ_t is not constant, as in conventional business cycle models, but time-varying. I assume that σ_t follows an AR(1) stochastic process itself

$$\ln \sigma_t = (1-\rho_\sigma)\ln \sigma + \rho_\sigma \ln(\sigma_{t-1}) + \eta_\sigma \epsilon_t^\sigma\ , \tag{2.34}$$

where the parameter $\rho_\sigma \in (0,1)$ captures the persistence of the uncertainty shock. The term ϵ_t^σ is a random variable following an i.i.d. standard normal distribution and it is the innovation to the uncertainty shock (also called a second-moment shock). Moreover, σ captures the mean volatility of the technology shock which also coincides with the steady state value of σ_t and η_σ is the constant standard deviation of ϵ_t^σ. Note that specifying the volatility process σ_t in logarithms (following Justiniano and Primiceri (2008)) implies that the standard deviation remains positive even under negative innovations ϵ_t^σ.

The uncertainty (or second-moment) shock ϵ_t^σ is a mean preserving shock. In other words, this pure uncertainty shock does not shift the level of aggregate technology. It only increases the variance of the distribution of the technology shock. We can think of ϵ_t^σ as temporarily inducing the technology process to have fatter tails and therefore increasing the probability that extreme realizations of A_t occur in the future. So, differently to a first-moment shock, ϵ_t, the agents' behaviour is not driven by changes in the model fundamentals. I specify uncertainty shocks focusing on the stochastic volatility of the TFP process to facilitate a direct comparison with benchmark macroeconomic models that study aggregate uncertainty.[5]

2.4 Calibration

The model is calibrated on US data at quarterly frequency. The structural parameters are either set to standard values employed in previous literature, or are calibrated to match a set of steady state targeted moments. The calibration for the benchmark model is summarised in Table 2.B.1.

Preferences. The subjective discount factor is set to $\beta = 0.995$ so that the model is consistent with a long-run annual real interest rate of 2%. The relative risk aversion coefficient is set to $\gamma = 1.5$. In the benchmark model I abstract from habit formation, setting $h = 0$, however in Appendix 2, I conduct sensitivity analysis for a utility specification with moderate ($h = 0.2$) and high ($h = 0.6$) degrees of habit formation consistently with the range of values reported in the literature. The results are robust to different specifications for habits.

Production. The elasticity of substitution for differentiated goods is set to

[5]Leduc and Liu (2016) experiment with uncertainty shocks specified as innovations to the stochastic volatility of demand and government spending shocks, and conclude that the impact of uncertainty were robust in different specifications.

$\eta = 10$ which implies a steady state markup over marginal costs equal to 11%, while the parameter that governs nominal price rigidities is set to $\Omega = 51$. This value for Ω is such that the slope of the linear New Keynesian Phillips Curve in the baseline model is the same as the NKPC slope of a Calvo pricing model in which the average price duration is 3 quarters.[6] Moreover, I assume that the c.d.f of the idiosyncratic productivity shocks $G(z)$ is log-normal. The mean of $G(\bullet)$ is normalised to $\mu_i = 0$ and the value of the standard distribution σ_i is equal to 0.2 as in Campolmi and Faia (2011).

Labour Market. The elasticity of job matches with respect to searching workers is set to $\alpha = 0.5$, within the range of estimates reported in Pissarides and Petrongolo (2001), and in line with the one used as a benchmark value in Blanchard and Gali (2010). The bargaining power parameter b is set to match α so that the Hosios condition holds. The total separation rate is set to $\lambda^{tot} = 0.055$, in line with the estimates reported by Davis et al. (1996), and I set $\frac{\lambda^x}{\lambda^{tot}}$ to 68%, as reported by Ramey et al. (2000). The parameters that remain to be calibrated are the scale parameter of the matching function μ, the real vacancy posting costs κ, the unemployment benefit ϕ, the home production parameter h^p, as well as firing costs F. I consider firing costs, F, to be zero in the benchmark model as in previous studies (including Krause and Lubik (2007) and Campolmi and Faia (2011)).[7] As is common practice in the literature, I target the steady-state unemployment rate and the steady-state job-filling probability, which are set to $U = 6.4\%$ following Leduc and Liu (2016) and $q^v = 0.7$ following Fujita and Ramey (2007). Additionally, I set the replacement ratio, $\frac{\phi}{w^{ss}}$, to 0.25 as in Hall and Milgrom (2008). This calibration strategy yields home production equal to $h^p = 0.54$, which implies a total steady-state value of non-labour, combining both home production as well as unemployment benefit, equal to 0.79. Additionally, our calibration yields $\mu = 0.77$,

[6] This value for the average price duration is within the range of empirical estimates based on microdata (Nakamura and Steinsson, 2013). Macroeconomic estimates typically assume a longer average price duration of 4 quarters which implies a higher value for Ω. As displayed in Appendix 2, our results remain robust to different degrees of price stickiness.

[7] Based on the difficulty of firing index of the World Bank 2008 Doing Business report, US ranks among the least rigid countries in terms of firing regulation, with firing costs amounting to eight or fewer weeks of weekly wage salaries. In section 2.7, I consider the impact of increasing firing costs in more detail.

$\kappa = 0.11$ and $\phi = 0.23$. The implied total cost of posting a vacancy at steady state, κv^{ss}, equals 1% of the steady state output. Both the total vacancy posting cost and the total steady-state value of non-labour implied by our calibration are conventional values commonly used in the literature (Hall and Milgrom, 2008).

Monetary Policy. I set the coefficients of the Taylor rule to the conventional values $\varphi_\pi = 1.5$ and $\varphi_y = 0.2$, and similarly to Leduc and Liu (2016). Under the baseline calibration, the smoothing parameter, φ_i, is equal to zero, but in the following sections I also explore how results change when applying monetary policy rules with high inertia, $\varphi_i = 0.8$.

Exogenous Shock Processes. The parameters of the technology shock are calibrated as in Basu and Bundick (2017). Specifically, I calibrate ρ_α, which is the persistence of the technology shock, to 0.9 and σ, which is the steady state volatility of the technology shock, to 0.01. For the calibration of the second-moment shock, I follow Leduc and Liu (2016) and set ρ_σ, which captures the persistence of the uncertainty shock, to 0.76. η_σ, which is the steady state standard deviation of the uncertainty shock, is set to 0.392.

2.5 Computational method

2.5.1 Solution

An increase in uncertainty is captured by an increase in the volatility of the technology shock process while keeping the level of the shock constant. In order to investigate the effects of this second-moment shock, I consider a third-order Taylor approximation of the policy functions of the agents and of the law of motion of the state variables around the zero-inflation steady state.

A third-order perturbation solution is necessary in order to study uncertainty shocks because, under a first-order approximation, the solution to the model is characterized by the certainty equivalence property. In other words, a standard linearisation or log-linearisation of the model implies that the optimal solution in the stochastic model (where agents know only the distribution of future shocks) is the same as the solution in the deterministic model (where agents perfectly know and anticipate the exact realization of future shocks). As a result, a first-order approximation of the model implies that only first moment shocks enter the decision rule of the agents and it fails to capture the effects of higher moments of the shock distribution.

Additionally, under a second-order approximation, volatility does play a role in the policy functions, but only indirectly. Uncertainty enters the policy functions as a constant effect and as the product of technology and volatility innovations (Fernandez-Villaverde et al., 2011). As a result, with a second-order approximation the effects of an uncertainty shock cannot be studied separately from first-moment shocks. However, under a third-order approximation volatility innovations enter the policy function directly, which allows us to isolate their effect and investigate how changes in their magnitude impact the behaviour of economic agents.

For the computation of the generalised impulse response functions (GIRFs) displayed in Section 2.7, I follow the algorithm described by Fernandez-Villaverde et al. (2011) and Born and Pfeifer (2014). Firstly, starting from the deterministic steady state, I simulate the model for 2,200 periods using third-order approximations. To account for initial shocks and to minimize the effect of the initial conditions, I subsequently drop the initial 2,000 periods which I consider as the burn-in period. I check for convergence using the remaining 200 periods, i.e., I check whether the maximum difference in these 200 quarters is larger than 1e-10, in which case I increase the simulation period to an additional 200 periods. Once convergence is verified, I interpret the final points after the burn-in period as the ergodic mean of the variables in the absence of shocks (also defined as the stochastic steady state). This is a crucial step for the construction of the generalised IRFs because under higher-order approximations the ergodic mean drifts away from the deterministic steady state of the variables.[8] As a result, the standard impulse responses, which are based on deviations from the deterministic steady state, may not converge or may lead to misleading results as they confound the impact of the second-moment shock with the transition to the new steady state. Instead, deviations from the

[8] For a detailed discussion see Fernandez-Villaverde et al. (2011).

ergodic mean should be considered. The next step of the algorithm involves conducting two simulations for a fixed number of periods. In Section 2.7 I consider 15 periods, with each of the two simulations starting from the ergodic mean of the associated variable. In the first simulation, the system is hit with no shocks. In the second simulation, I hit the system in the first period with a one-time uncertainty shock ϵ_t^σ (that is a one-standard-deviation shock on the volatility of the technology process as is commonly done in related literature). The GIRFs reported are the percentage deviations between the two simulations. Due to the instability of the approximated solution, a common feature of higher-order approximated solutions, I impose pruning before solving the model.[9]

2.6 Discussion

Before proceeding with the quantitative analysis of the model, I analyse why I built the model with those particular frictions and discuss how they relate to the amplification mechanisms of uncertainty shocks.

Both nominal price rigidities and search frictions are crucial for amplification and the ability of the model to replicate key co-movements in the data. Starting with the amplification role of price stickiness, which was first explored by Basu and Bundick (2017), in an NK setting a drop in aggregate demand translates to lower demand also for input goods as wholesale firms fail to fully adjust through the price margin. Intermediate good firms react to the decrease in the expected value of a job match by decreasing labour demand leading to higher unemployment. This results in lower household income which intensifies the initial drop in aggregate demand. In the case of flexible product markets instead, final good prices can adjust sufficiently and can fully absorb the drop in aggregate demand without transmitting the uncertainty shock downstream.

The search-and-matching framework is also important for the propagation of uncertainty (Leduc and Liu, 2016). In an environment with low search frictions (i.e., low κ), a drop in vacancy posting due to an uncertainty shock results in a muted response of unemployment. More formally, with low search frictions, the Job Creation Curve intersects with the inelastic part of the Beveridge Curve while

[9] For a detailed analysis on pruning see the Appendix 2.

under high search frictions the intersection occurs at the elastic part of the Beveridge Curve. As a result, for the same change in vacancy posting, the response of unemployment will be smaller in the former case, so the effects of uncertainty are amplified in the latter case.

The key channel that drives the agents' response to uncertainty shocks in this framework is the precautionary savings channel, namely the incentive of households to temporarily decrease consumption and increase savings in an environment of heightened uncertainty. More formally, the CRRA preferences used in the model specification imply a positive third-order derivative of the utility function which is a necessary and sufficient condition for the representative household to be prudent (Kimball, 1990). Due to prudence, uncertainty about the evolution of future income creates a precautionary savings motive.[10] Agents hoard cash in order to create a buffer wealth stock in anticipation of future adverse shocks and decrease consumption. The drop in current aggregate demand leads to a drop in the relative price of input goods due to the countercyclicality of markups. As a result, the expected profits of intermediate good firms drop and the value of a new job match falls as well. Firms react to the decrease in the match value by reducing their demand for labour. As jobs become harder to find and retain, unemployment increases, the household income decreases further and the initial drop in aggregate demand is compounded.

Uncertainty can also impact firm behaviour through the real option to "wait and see". However, it should be noted that in the current framework this channel is not operational.[11] Even though, under a costly matching process, hiring of labour resembles investment under irreversible costs (due to the presence of fixed sunk vacancy posting costs) the free entry condition of firms acts to set the value of the

[10]Prudence is a measure of the willingness to save for future uncertainty. Its intensity is measured by $P(x) = \frac{-u'''(x)}{u''(x)}$, where x stands for wealth. As shown in Kimball (1990), a necessary and sufficient condition for prudence is $u''' > 0$. For the CRRA preferences specified in equation (1), this condition holds and additionally $\frac{\partial P(x)}{\partial x} = -\frac{\gamma+1}{x^2} < 0$, so the intensity of precautionary saving is higher for lower levels of wealth.

[11]This is true for the entire class of models that study search frictions in the context of a representative firm in which a free-entry condition holds, including previous studies by Leduc and Liu (2016) and Guglielminetti (2016). For a detailed discussion on this topic see Den Haan et al. (2020).

real option of waiting to zero in every period.[12]

2.7 Quantitative analysis

I begin the analysis by investigating the dynamic response of the system to an uncertainty shock in a benchmark model that features endogenous job separations. To isolate the importance of the job-destruction channel, I compare the responses of key variables under a scenario where job separations are exogenous. I then study how the size of firing costs matters for the amplification of aggregate uncertainty and discuss sensitivity of results to different specifications of the monetary policy rule. To facilitate comparison with existing studies, I focus on uncertainty related to the evolution of the technology process.

2.7.1 The recessionary effects of uncertainty shocks

The role of endogenous separations

In Figure 2.1, I compare the impact of a positive uncertainty shock in the benchmark economy (which features endogenous job separations and no firing costs, $F = 0$) and in a counterfactual scenario where endogenous job separations are shut down. In both cases, the economy responds to uncertainty in a way that is in line with the intuition described in section 2.6.

After the uncertainty shock hits the system, households decrease consumption, consistently with the precautionary saving motive. The decline in consumption results in a drop in the relative price of the input goods due to the countercyclicality of the price markups. As intermediate firms' profits decline, the value of a job match for firms drops as well. In the benchmark economy, firms react by demanding a higher cutoff productivity above which they are willing to maintain job matches. More specifically, from inspecting Eq. 2.12, it can be seen that firms respond to the reduction in the expected continuation value of the job match by

[12]The impact of the real option channel on labour market variables is theoretically ambiguous in the presence of endogenous job separations. Higher uncertainty induces firms to be more cautious towards posting vacancies as there is a higher probability that the continuation value of the job match will not be sufficiently high to compensate for the vacancy posting costs, leading to lower job-finding rate. However, the option to wait channel also makes firms more cautious towards destroying job-matches, leading to lower separation rate. The relative strength of the two effects will determine the overall impact of the real option channel on employment. Studying this channel lies outside the scope of this paper and is deferred to future research.

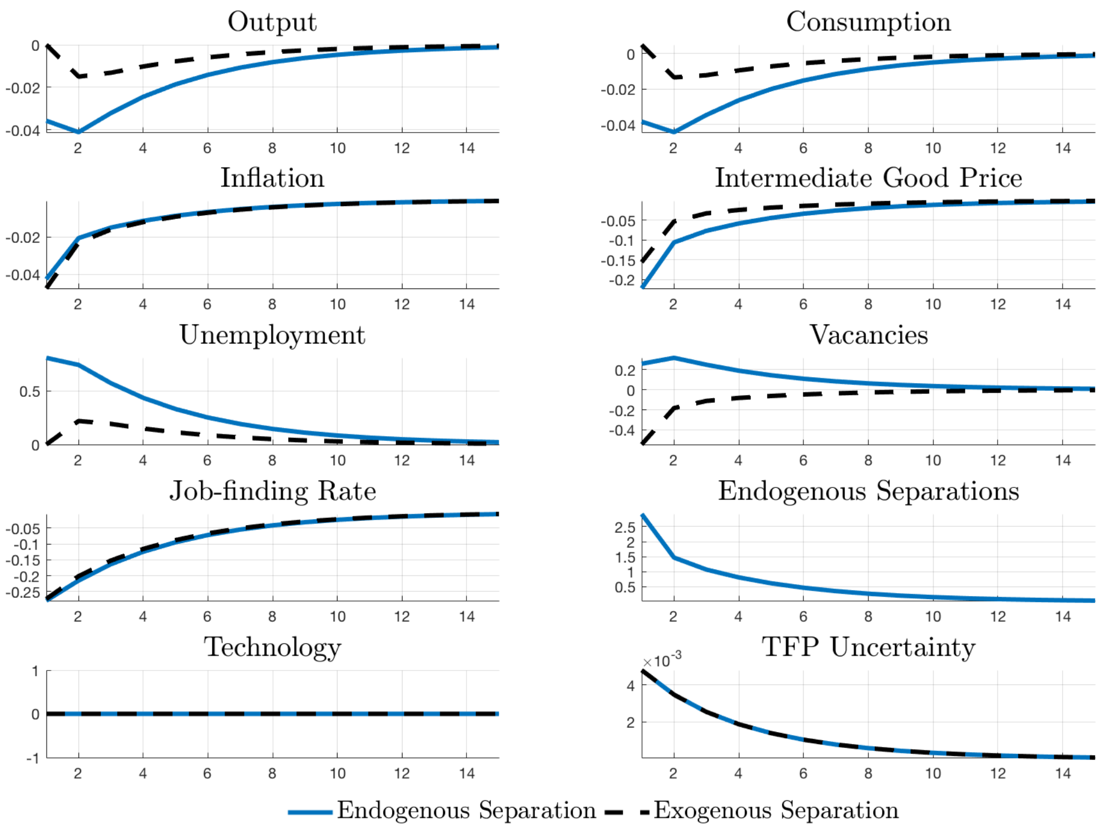

Figure 2.1: Impact of uncertainty shock (a)

Note: Impulse Response Functions to a one standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state) with the exception of the IRFs of the technology and the uncertainty shock that are in terms of absolute deviations. The horizontal axis depicts periods in quarters.

requiring a higher flow profit from the match with the cutoff worker, so that on the margin they remain indifferent between maintaining the employment relationship or destroying the match. The increase in the productivity cutoff level z^c implies a higher endogenous job-separation rate $\lambda_t^n = G(z_t^c)$ which feeds into higher unemployment and further decreases the household income.

Interestingly, despite the drop in the value of job matches, vacancies increase in the benchmark economy, contrary to the case with exogenous separations where the lower match value induces firms to reduce vacancy postings. This counterfactual dynamic behaviour of vacancies in the baseline case results from the "echo effect" in search models with an endogenous job destruction channel, and it is linked to the free-entry condition of firms into the matching market (Fujita, 2005). As the uncertainty shock increases separations and unemployment, it also increases the chance that a firm will successfully be matched with an unemployed searcher, which raises the incentive of firms to enter the matching market and post more vacancies. This pushes up the job finding rate of searchers, which is indistinguishable in the benchmark economy and the model with exogenous separations, despite the more pronounced increase in unemployment in the former case. As will be discussed in detail later, the "echo effect" and the countercyclical behaviour of vacancies hinges on the size of firing costs.

Both the increase in job separations and the drop in the job-finding rate contribute to the sharp increase in unemployment in the benchmark economy which intensifies the precautionary motive of households and leads to a further decline in output. The relative strength of the response in vacancies and unemployment will determine the dynamics of tightness which is crucial for wage determination. As shown in the Appendix 2, the latter dominates in the benchmark model leading to a more pronounced drop of tightness and pushing down real wages.

An important finding of this experiment is that the endogenous separation channel helps to magnify the macroeconomic impact of uncertainty, as illustrated by the IRFs in Figure 2.1. The intuition is straightforward. This channel creates an additional margin of adjustment for firms in response to lower aggregate demand, which contributes to higher unemployment on top of the job-creation channel which is operational in the model with exogenous separations.

It is worth noting that even though the real price of intermediate goods suffers a larger hit under the baseline scenario, inflation responds relatively less when job separations are endogenous. This may seem initially puzzling as the New Keynesian Phillips Curve links, to a first order, inflation to the firms' real marginal cost, p_w. However, as noted in Fernandez-Villaverde et al. (2011) and Born and Pfeifer (2021), in the presence of uncertainty there is an additional channel that determines inflation: firms' precautionary pricing behaviour. With sticky prices, uncertainty about future demand introduces the following asymmetry for firms: if the reset price is too low firms will incur losses as they have to meet a higher demand at this lower price. On the other hand, if the reset price is too high, demand will be lower but firms will be compensated by the higher markup. This asymmetry, which can be described as an inverse Oi–Hartman–Abel-effect, explains the inflationary bias of firms under uncertainty. Under both scenarios, the negative pressures on inflation due to lower aggregate demand dominate the positive pressures due to precautionary pricing leading inflation to respond negatively to the uncertainty shock. The difference in the inflation responses is due to the relatively stronger precautionary pricing motive of firms under the baseline model with endogenous job separations arising from the nonlinear Phillips Curve.[13]

2.7.2 The job-creation vs job-destruction margin

To better understand the role of the two labour adjustment margins and explore how firing costs are relevant for the amplification mechanism in the model, I recalibrate the model to different degrees of firing costs, keeping the targeted moments unchanged. Specifically, I compare the dynamic responses in the limit case of $F = 0$ (benchmark model) to the case where firing costs are set to levels observed in the Euro Area,[14] as well as an intermediate case. What I find is that the amplification of labour market frictions is decreasing in the size of the firing costs but the differences across the three scenarios are quantitatively small.

Lower firing costs imply that it is less costly for firms to adjust along the extensive margin of their workforce via match separations. As a result, in response to the same uncertainty shock, firms will drive up their separation rate relatively more when they face low firing costs, which in turn explains the higher cutoff productivity z^c in the baseline scenario.

The higher separation rate in the baseline scenario results in a larger increase of the unemployment rate and thus in more negative aggregate demand effects, and relatively lower consumption and output. For higher firing costs, the job-

[13] More formally, the nonlinear Phillips Curve includes the variance inflation term and the covariance between inflation and stochastic discount factor term which is higher in the baseline scenario.

[14] The differences between US and EA firing costs have been identified as an important candidate for explaining the differences in the degree of flexibility in the two labour markets (the so called "Eurosclerosis" phenomenon). This experiment speaks to this debate but in the context of uncertainty shocks. Specifically, in the high FC scenario, I set firing costs equal to 13% of the average steady state wage. This amounts to half the value cited by the World Bank 2008 Doing Business report for the Euro Area countries as the model abstracts from severance payments which contribute significantly to businesses layoff costs. In the intermediate case, I consider the mid-point of $F^{ss} = 6.5\% \, \tilde{w}^{ss}$.

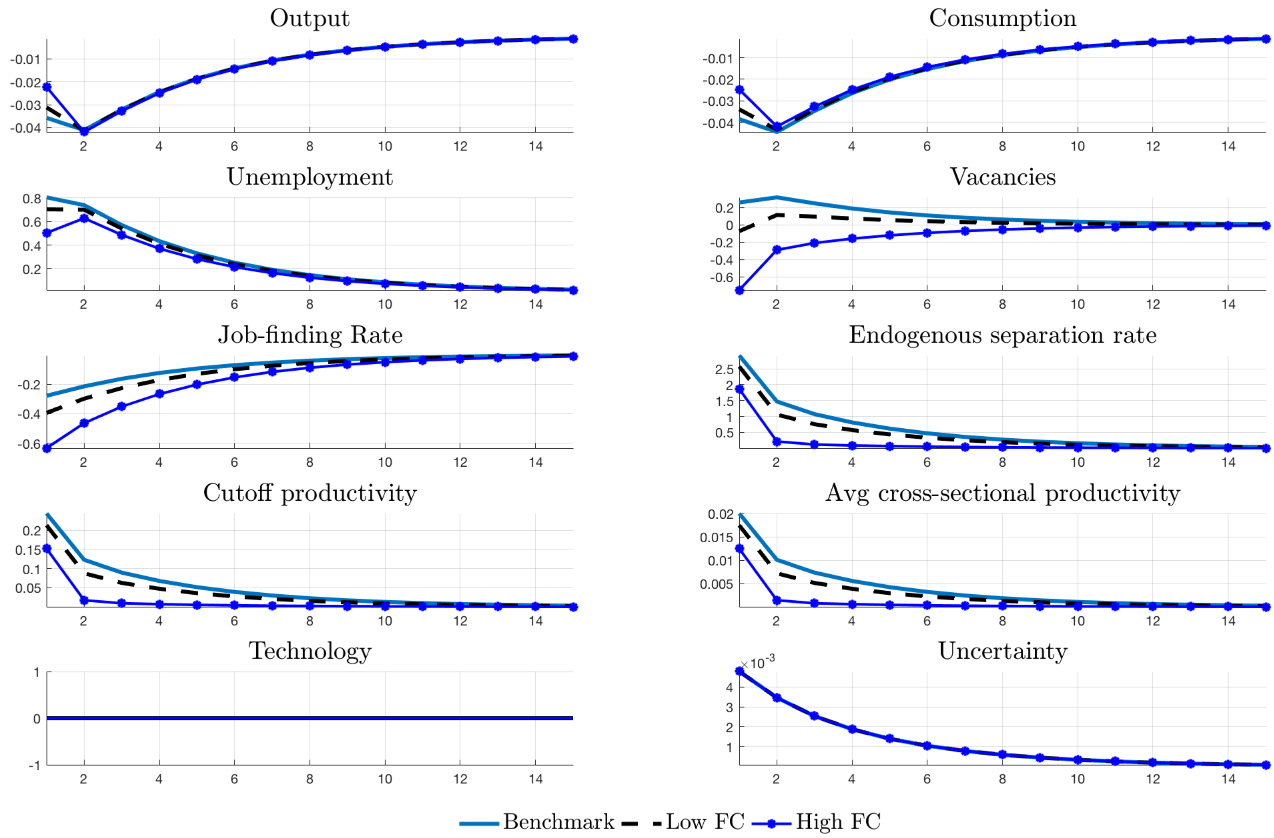

Figure 2.2: Impact of uncertainty shock under different firing costs

Note: Impulse Response Functions to a one standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state) with the exception of the IRFs of the technology and the uncertainty shock that are in terms of absolute deviations. The horizontal axis depicts periods in quarters.

separation channel is mitigated, leading to a smaller increase in unemployment and a weaker motive for precautionary savings.

Even though responses for most variables differ only slightly when considering alternative calibrations of F, the dynamic response of vacancies differs substantially with the size of firing costs. For sufficiently high firing costs (at the levels observed in the Euro Area for instance), the "echo effect" of endogenous job destruction is muted. Firms respond to the decrease in the value of job matches by reducing rather than increasing vacancy postings. Intuitively, under higher firing costs, a larger part of the match surplus will be wasted in the future in the event that the job-match becomes unprofitable, driving vacancy postings down and resulting in a relatively lower job-finding rate as well.

How unemployment behaves in the presence of uncertainty shocks is ultimately determined by the relative strength of the job-creation and job-destruction channels. Higher firing costs imply a weaker endogenous separation rate but a stronger negative effect on job-finding rates. As illustrated in Figure 2.2, unemployment increases marginally more when firing costs are smaller, pointing to a stronger effect coming from the job-destruction channel.

2.7.3 The role of monetary policy

Next, I explore how different monetary policy rules affect the propagation of uncertainty shocks. The departure point for this analysis are recent findings by Fasani and Rossi (2018) who challenge the conclusion of Leduc and Liu (2016) that uncertainty shocks behave like aggregate demand shocks. More specifically, Fasani and Rossi (2018) argue that the response of inflation crucially depends on the monetary policy rule adopted. I perform a similar analysis in the presence of endogenous job separations.

Figure 2.3 displays the response of the main macroeconomic variables under the following monetary policy rules: (i) the baseline case, with $\varphi_\pi = 1.5$, $\varphi_y = 0.2$, $\varphi_i = 0$ (ii) strong inflation targeting, with $\varphi_\pi = 2$, $\varphi_y = 0.2$, $\varphi_i = 0$ (iii) weak inflation targeting, with $\varphi_\pi = 1.2$, $\varphi_y = 0.2$, $\varphi_i = 0$ and (iv) inflation and output gap targeting with interest-rate smoothing $\varphi_\pi = 1.5$, $\varphi_y = 0.2$, $\varphi_i = 0.8$, which is an empirically plausible and commonly used specification.

Firstly, this exercise highlights that the responses of the key macroeconomic variables remain qualitatively unchanged when applying different Taylor rules, but a more responsive monetary policy stance helps to cushion the negative impact of the uncertainty shock and stabilise the economy.

Secondly, this analysis confirms the critical role of monetary policy for the behaviour of inflation. Under a Taylor rule that places higher weight on smoothing, the quantitative response of inflation is small. These inflation dynamics imply that the inflationary pressures of uncertainty, which arise from the precautionary pricing of firms, broadly offset the deflationary pressures due to lower aggregate demand when the monetary authority acts with delay in stabilising the economy.

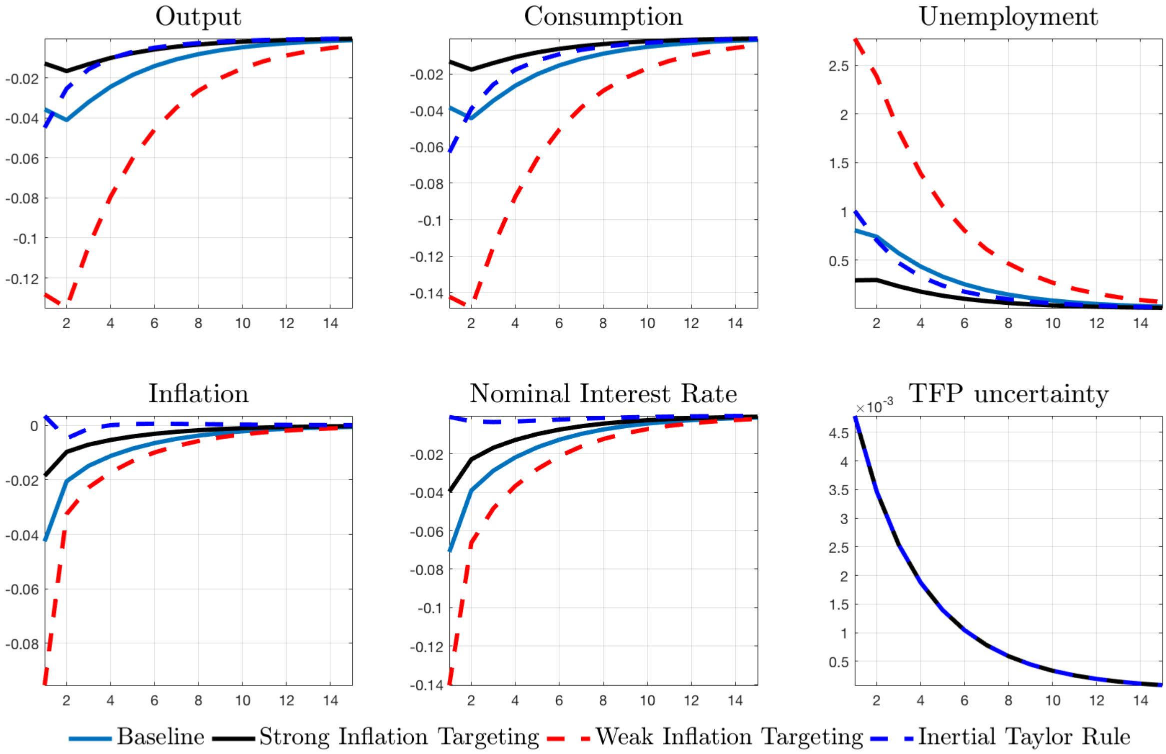

Figure 2.3: Impact of uncertainty shock under different Taylor rule specifications

Note: Impulse Response Functions to a one standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state) with the exception of the IRFs of the TFP uncertainty shock that are in terms of absolute deviations. The horizontal axis depicts periods in quarters.

In contrast, under Taylor rules that imply an immediate response of monetary authorities to inflation divergence from target, the precautionary pricing motive is muted and deflationary pressures dominate. This result is in line with the findings of Fasani and Rossi (2018).

2.8 Conclusion

This paper aims to contribute to the fast-growing literature on uncertainty by examining how the job destruction channel affects the propagation of uncertainty shocks and by exploring the role of firing restrictions. My analysis is conducted through the lens of a New Keynesian DSGE model with frictional labour markets which is calibrated to match salient features of the US economy. Uncertainty is modelled as a shock to the time-varying volatility of the technology process.

I find that the presence of endogenous job separations amplifies the negative impact of uncertainty on the real economy as it contributes to higher unemployment and intensifies the precautionary savings behaviour of prudent households. Additionally, I explore the interaction between firing costs and uncertainty. Firing costs affect the job-creation and job-destruction components of unemployment in opposite directions, with higher firing cost implying a relatively weaker job separation incentive of firms but also a lower incentive for vacancy postings which feeds into a lower job-finding rate for workers. The relative strength of these two components determines the overall response of unemployment to uncertainty. I find that an increase in firing costs slightly improves the resilience of the economy to uncertainty, which is consistent with a relatively stronger contribution of the job-destruction channel to the precautionary behaviour of households.

Finally, in this chapter I consider how different monetary policy rules interact with labour market frictions in the presence of heightened uncertainty. I find that under reasonable specifications of the Taylor rule, that allow for interest-rate smoothing, uncertainty shocks do not behave like negative aggregate demand shocks, as they push real activity downwards but result in broadly unchanged inflation responses. This finding complements the work of Fasani and Rossi (2018) who reach a similar conclusion in a framework without endogenous job separations.

The analysis of this chapter is conducted through a representative firm framework. A limitation of this setup is that the real option to "wait-and-see" is not operational, limiting the channels through which uncertainty shocks can influence the behaviour of economic agents. It would be interesting in future work to expand the analysis of the endogenous job separation margin to a heterogeneous firm framework and study the interactions between the two channels.

By studying the importance of endogenous job-separations and firing in the context of uncertainty shocks this paper speaks to the ongoing debate regarding post-Covid labour market policy design. Indeed, the job-destruction adjustment margin is particularly relevant for the evaluation of labour market policies which differ in their employee-retention focus. An important dimension of this debate relates to the costs of hysteresis that may arise due to the massive dislocation of workers and the subsequent loss of human, knowledge and organizational capital. A fruitful avenue for future research could be to introduce a hysteresis mechanism[15] in the model and investigate the impact of uncertainty shocks taking also into account hysteresis costs.

Finally, it is worth noting that in our analysis monetary policy is unrestricted in its capacity to reduce interest rates in order to accommodate the uncertainty shock. However, if the monetary authority faces limitations in its ability to use conventional instruments, because of the zero lower bound constraint for instance, the impact of uncertainty shocks may differ.[16] Exploring the role of the ZLB in the presence of endogenous job separations is another interesting extension of this chapter.

[15]This could be achieved by introducing a human capital depreciation mechanism in the spirit of Esteban-Pretel and Faraglia (2010) and Laureys (2014).

[16]Recent studies suggest that the ZLB leads to a higher uncertainty multiplier (see Cacciatore and Ravenna (2020), Basu and Bundick (2017) and Born and Pfeifer (2014) for a discussion on the importance of the ZLB uncertainty multiplier).

Acknowledgements I would like to thank my supervisor Andrea Ferrero for his invaluable support and guidance. I would also like to thank Francesco Zanetti and Harris Dellas for helpful discussions and comments. I am grateful for the comments of the participants at the 2nd International Conference in Applied Theory, Macro and Empirical Finance (AMEF) and the Macroeconomics Working Group at the University of Oxford. I would like to thank particularly Rajssa Mechelli, Alex Haas, Genevieve Nelson, Lukas Hensel and Timo Reinelt for their useful feedback. This work was supported by the Economic and Social Research Council (award number: ES/J500112/1).

Appendices of chapter 2

Description of appendix to Chapter 2

Section 2.A derives the model equations, while Section 2.B summarizes the calibration strategy. Section 2.C discusses the reasons why pruning was conducted in order to solve the model. Finally, section 2.D presents the figures discussed in Chapter 2, as well as additional experiments and sensitivity analysis.

2.A Mathematical appendix

Households

Households maximise the present discounted value of their utility function

$$U_t = \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \frac{(C_t - hC_{t-1})^{1-\gamma}}{1-\gamma} \tag{2.35}$$

Subject to the following sequence of budget constraints

$$C_t + \frac{B_t}{P_t} = R_{t-1}\frac{B_{t-1}}{P_t} + \tilde{w}_t N_t + d_t + \phi(1-N_t) + t_t \tag{2.36}$$

The Lagrangian associated with this problem is

$$\mathcal{L}_t = \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left\{ \left(\frac{(C_s - hC_{s-1}^{1-\gamma}}{1-\gamma} \right) - \Lambda_s \left(C_s + \frac{B_s}{P_s} - R_{s-1}\frac{B_{s-1}}{P_s} - \tilde{w}_s N_s - d_s - \phi(1-N_s) - t_s \right) \right\} , \tag{2.37}$$

where Λ_s is the Lagrange multiplier for the budget constraint and it captures the marginal utility of relaxing the constraint by one unit of wealth.

FOCs with respect to bond holdings yield

$$\frac{\partial \mathcal{L}}{\partial B_t} = 0 \therefore \frac{\Lambda_t}{P_t} = \beta R_t \mathbb{E}_t \left(\Lambda_{t+1} \frac{1}{P_{t+1}} \right) \tag{2.38}$$

The combination of the two FOCs yields the Euler Equation

$$1 = \mathbb{E}_t \beta \left\{ \frac{\Lambda_{t+1}}{\Lambda_t} \right\} \frac{R_t}{\pi_{t+1}} \tag{2.39}$$

Retail firms

Final good producers choose the amount of input good $y_t(j)$ for $j \in [0,1]$ in order to solve the following static profit maximisation problem

$$\max P_t Y_t - \int_0^1 P_t(j)\, y_t(j) dj \tag{2.40}$$

subject to the production technology which is a Dixit-Stiglitz aggregator that transforms intermediate goods into final consumption goods according to

$$Y_t = \left[\int_0^1 y_t(j)^{\frac{\eta-1}{\eta}} dj \right]^{\frac{\eta}{\eta-1}} \tag{2.41}$$

The related Lagrangian function is

$$\mathcal{L} = P_t Y_t - \int_0^1 P_t(j)\, y_t(j) dj - \lambda \left(Y_t - \left[\int_0^1 y_t(j)^{\frac{\eta-1}{\eta}} dj \right]^{\frac{\eta}{\eta-1}} \right) \tag{2.42}$$

The FOCs yield

$$y_t(j) = \left(\frac{P_t(j)}{\lambda} \right)^{-\eta} Y_t \tag{2.43}$$

This implies that for any two input goods i, j, the following holds

$$\frac{y_t(j)}{y_t(i)} = \left(\frac{P_t(j)}{P_t(i)} \right)^{-\eta} ,$$

We can rewrite the last equation as

$$\begin{aligned} y_t(i) \int_0^1 P_t(j)^{1-\eta} dj &= P_t(i)^{-\eta} \int_0^1 y_t(j) P_t(j) dj \\ \therefore y_t(i) &= \left(\frac{P_t(i)}{P_t} \right)^{-\eta} Y_t \end{aligned} \tag{2.44}$$

The above is derived after observing that the zero profit condition for the perfectly competitive retail firms implies that

$$Y_t P_t = \int_0^1 y_t(j) P_t(j) dj \tag{2.45}$$

and after defining the associated price index P_t as

$$P_t = \left[\int_0^1 P_t(j)^{1-\eta} dj \right]^{\frac{1}{1-\eta}} \tag{2.46}$$

Wholesale firms

Firms at the second stage of production solve for the optimal price $P_t^*(j)$ which maximizes the present discounted stream of expected profits

$$\max_{P_t^*(j)} \mathbb{E}_t \sum_{i=0}^{\infty} \beta^i \left(\frac{\Lambda_{t+i}}{\Lambda_t}\right) \left(\left[\left(\frac{P_{t+i}(j)}{P_{t+i}} \right) - MC^r_{t+i}(j) \right] y_{t+i}(j) - \frac{\Omega}{2} \left(\frac{P_{t+i}(j)}{\bar{\pi}\, P_{t+i-1}(j)} - 1 \right)^2 Y_{t+i} \right), \tag{2.47}$$

subject to two constraints. Firstly, wholesalers take the demand schedule of retailers as given

$$y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\eta} Y_t \tag{2.48}$$

Secondly, the real marginal cost of production is the relative price of the input good

$$MC_t^r(j) = MC_t^r = p_t^w, \forall j \tag{2.49}$$

Differently than Calvo pricing, all firms face the same problem and thus will choose the same price and producing quantity. Substituting the constraints in the objective function, we can derive the optimal price setting equation

$$\begin{aligned} &\left(\frac{\Lambda_t}{\Lambda_0}\right) \left\{ (1-\eta) \left(\frac{P_t(j)}{P_t} \right)^{-\eta} \frac{Y_t}{P_t} + \eta\, p_t^w \left(\frac{P_t(j)}{P_t} \right)^{-(1+\eta)} \frac{Y_t}{P_t} - \Omega \left(\frac{P_t(j)}{\pi P_{t-1}(j)} - 1 \right) \frac{1}{\pi P_{t-1}(j)} \right\} + \\ &\quad + \mathbb{E}_t\, \beta \left(\frac{\Lambda_{t+1}}{\Lambda_0} \right) \Omega Y_{t+1} \left(\frac{P_{t+1}(j)}{\pi P_t(j)} - 1 \right) \frac{P_{t+1}(j)}{\pi P_t(j)^2} = 0 \end{aligned} \tag{2.50}$$

Taking into account the symmetric equilibrium, $P_t(j) = P_t\, \forall\, j$, defining $\pi_t = \frac{P_t}{P_{t-1}}$, and rearranging,

$$\begin{aligned} &(1-\eta) + \eta\, p_t^w - \Omega \left(\frac{\pi_t}{\pi} - 1 \right) \frac{\pi_t}{\pi} + \beta\, \mathbb{E}_t \left(\frac{\Lambda_{t+1}}{\Lambda_t} \right) \frac{Y_{t+1}}{Y_t} \Omega \left(\frac{\pi_{t+1}}{\pi} - 1 \right) \frac{\pi_{t+1}}{\pi} \\ &\therefore p_t^w = \frac{\eta - 1}{\eta} + \frac{\Omega}{\eta} \left[\left(\frac{\pi_t}{\pi} - 1 \right) \frac{\pi_t}{\pi} - \beta\, \mathbb{E}_t \left(\frac{\Lambda_{t+1}}{\Lambda_t} \right) \frac{Y_{t+1}}{Y_t} \left(\frac{\pi_{t+1}}{\pi} - 1 \right) \frac{\pi_{t+1}}{\pi} \right] \end{aligned} \tag{2.51}$$

Wage schedule

The Nash Bargaining wage solution can be derived as the solution to

$$b\mathcal{S}_t(z) = (1-b)\mathcal{S}_t^W(z) \tag{2.52}$$

Replacing $\tilde{\mathcal{S}}_t^W(z)$ with $\frac{b}{1-b}\tilde{\mathcal{S}}_t(z)$ and substituting $\mathcal{S}_t(z) = \mathcal{J}_t^F(z) + F$, as in equation (2.14) yields the following

$$\mathcal{S}_t^W(z) = w_t(z) - \mathcal{U}_t + \frac{b}{1-b}\beta(1-\lambda^x)\mathbb{E}_t\left(\frac{\lambda_{t+1}}{\Lambda_t}\right)\Big((1 - G(z_{t+1}^c)(\tilde{\mathcal{J}}_{t+1} + F)\Big) \ . \tag{2.53}$$

Further substitution based on the job creation condition, described by equation (2.11), yields the following

$$\mathcal{S}_t^W(z) = w_t(z) - \mathcal{U}_t + \frac{b}{1-b}\beta(1-\lambda^x)\mathbb{E}_t\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)F + \frac{b}{1-b}\frac{\kappa}{q_t^v} \ . \tag{2.54}$$

With additional algebraic manipulations we can rewrite the above condition as

$$b(p_t^w A_t z_t - w(z_t) + \frac{\kappa}{q_t^v} + F) = (1-b)(w(z_t) - \mathcal{U}_t + \frac{b}{1-b}\beta(1-\lambda^x)\mathbb{E}_t(\frac{\Lambda_{t+1}}{\Lambda_t})F + \frac{b}{1-b}\frac{\kappa}{q_t^v})$$

$$w(z_t) = b\left(p_t^w A_t z_t + (1 - (1-\lambda^x)\mathbb{E}_t\beta(\frac{\Lambda_{t+1}}{\Lambda_t})F\right) + (1-b)\mathcal{U}_t \ . \tag{2.55}$$

Substitution of the outside option of workers, given by equation (2.16), into the expression above yields the expression for the Nash bargaining wage $w_t(z)$ in the main text

$$w(z_t) = (1-b)(\phi + h^p) + b\left(p_t^w A_t z_t + \kappa\frac{q_t^u}{q_t^v} + (1 - (1-\lambda^x)(1-q_t^u)\mathbb{E}_t\beta\frac{\Lambda_{t+1}}{\Lambda_t})F\right) \ . \tag{2.56}$$

2.B Calibration

TABLE 2.B.1. **PARAMETER CALIBRATION**

Parameters	description	Value	References/Targets
β	subjective discount factor	0.995	2% annual real interest rate
γ	relative risk aversion	1.5	Literature
h	internal habits persistence	0	Baseline Calibration
η	elasticity of substitution between differentiated goods	10	Target 11% markup
Ω	price stickiness	51	Map to Calvo NKPC with 3Q price duration
μ_i	mean of i.i.d shocks distribution	0	Normalisation
σ_i	s.d of i.i.d shocks distribution	0.2	Campolmi and Faia (2011)
μ	matching efficiency	0.77	$U^{ss} = 6.4\%$
α	elasticity of matches to workers	0.5	Conventional value
b	workers' bargaining power	0.5	Hosios condition holds
λ^{tot}	total separation rate	0.055	Davis et al. (1996)
ϕ	unemployment benefit	0.23	Replacement rate 25%
κ	vacancy posting costs	0.11	Target $\kappa v^{ss} = 1\% Y^{ss}$
h^p	home production	0.52	$q^v = 0.7$
ϕ_π	Taylor-rule coefficient on inflation	1.5	Baseline Calibration
ϕ_y	Taylor-rule coefficient on output	0.2	Baseline Calibration
ϕ_i	Taylor-rule smoothing coefficient	0	Baseline Calibration
	Parameters for the shock process		
ρ_a	persistence of technology shock	0.9	Basu and Bundick (2017)
ρ_σ	persistence of uncertainty shock	0.76	Leduc and Liu (2016)
σ	steady state volatility of technology shock	0.01	Basu and Bundick (2017)
η_σ	steady state volatility of uncertainty shock	0.39	Leduc and Liu (2016)

2.C Pruning

One of the main challenges that arises from higher-order perturbation methods is that they often generate explosive paths for the system regardless of the dynamics of the original model, i.e., even when the corresponding linearized solution is stable (Lombardo and Uhlig, 2018). The reason why higher-order approximations imply spurious simulations, namely simulations which are unrelated to the dynamics of the exact solution, is that even a relatively small shock suffices to push the second- and third-order terms of the approximated policy function far enough from the steady state for the system to diverge. In other words, the non-linear representation of the state-space is at the heart of the instability of higher-order approximated systems. One solution to this challenge is pruning. Pruning, as a technique to ensure stability, was first suggested by Kim et al. (2008) for second-order approximations to the solutions of stochastic models. This technique was subsequently generalized by Andreasen et al. (2018) for third-order approximations. The basic intuition behind this method is that the higher-order terms that generate instability are dropped or replaced with associated lower-order terms so that the pruned approximation generates stable dynamics.This Appendix presents in further detail how pruning works and provides a demonstration of how it can be implemented.

As outlined above, one solution to this problem, proposed by Kim et al. (2008), is to drop the terms which have higher-order effects than the approximation order. In that way, we eliminate the source of instability and iterating forward in time the pruned approximated system generates stationary simulated paths. The following demonstration of how pruning works is largely based on Andreasen et al. (2018).

Assuming that $\mathbf{y}_t \in \mathbb{R}^n$ is the vector of control variables and $\mathbf{x}_t \in \mathbb{R}^m$ is the vector of state variables, and that in both vectors variables are expressed in terms of deviations from their steady state then the following unpruned state-space system describes the solution to the DSGE model

$$\mathbf{y}_t = \mathbf{g}(\mathbf{x_t}; \sigma)$$
$$\mathbf{x}_{t+1} = \mathbf{h}(\mathbf{x}_t; \sigma) + \sigma \mathbf{u}_{t+1}$$

where $\mathbf{g}(\cdot)$ is the policy function, the second equation captures the law of motion of the state variables and σ is the perturbation parameter which controls the variance of the disturbances $\mathbf{u}_t$. We assume that $\mathbf{u}_t$ is i.i.d without specifying its distribution. Usually it is not possible to find an exact solution for $\mathbf{g}(\mathbf{x_t};\sigma)$ and $\mathbf{h}(\mathbf{x}_t;\sigma)$. Instead, numerical approximations are used. The third-order Taylor approximation to the law of motion is

$$\begin{aligned}\mathbf{x}_{t+1} = \mathbf{h_x}\mathbf{x}_t + \frac{1}{2}\mathbf{H_{xx}}(\mathbf{x}_t \otimes \mathbf{x}_t) + \frac{1}{6}\mathbf{H_{xxx}}(\mathbf{x}_t \otimes \mathbf{x}_t \otimes \mathbf{x}_t)\\ +\frac{1}{2}\mathbf{h}_{\sigma\sigma}\sigma^2 + \frac{3}{6}\mathbf{h}_{\sigma\sigma\mathbf{x}}\sigma^2\mathbf{x}_t + \frac{1}{6}\mathbf{h}_{\sigma\sigma\sigma}\sigma^3 + \sigma\mathbf{u}_{t+1}\end{aligned}$$

where $\mathbf{h_x}$ is the $m \times m$ matrix of first order derivatives of $\mathbf{h}(\cdot)$ with respect to $\mathbf{x}_t$, $\mathbf{H_{xx}}$ is the $m \times m^2$ matrix of derivatives of $\mathbf{h}(\cdot)$ with respect to $(\mathbf{x}_t, \mathbf{x}_t)$, $\mathbf{H_{xxx}}$ is the $m \times m^3$ matrix with the derivatives with respect to $(\mathbf{x}_t, \mathbf{x}_t, \mathbf{x}_t)$, $\mathbf{h}_{\sigma\sigma}$ is the $m \times 1$ matrix of derivatives related to (σ, σ), $\mathbf{h}_{\sigma\sigma\mathbf{x}}$ is the $m \times m$ matrix of derivatives with respect to $(\sigma, \sigma, \mathbf{x}_t)$ and $\mathbf{h}_{\sigma\sigma\sigma}$ is the $m \times 1$ matrix with the derivatives related to (σ, σ, σ).

The above Taylor series expansion is an unpruned approximation to the law of motion of the state variables. In order to derive the pruned approximation, we first decompose the state variables in their first-order, second-order and third-order effects: $\mathbf{x}_t^f$, $\mathbf{x}_t^s$, and $\mathbf{x}_t^t$ respectively. The above equation can be rewritten as

$$\begin{aligned}\mathbf{x}_{t+1} = \mathbf{h_x}(\mathbf{x}_t^f + \mathbf{x}_t^s + \mathbf{x}_t^t) + \frac{1}{2}\mathbf{H_{xx}}((\mathbf{x}_t^f + \mathbf{x}_t^s + \mathbf{x}_t^t) \otimes (\mathbf{x}_t^f + \mathbf{x}_t^s + \mathbf{x}_t^t))\\ + \frac{1}{6}\mathbf{H_{xxx}}((\mathbf{x}_t^f + \mathbf{x}_t^s + \mathbf{x}_t^t) \otimes (\mathbf{x}_t^f + \mathbf{x}_t^s + \mathbf{x}_t^t) \otimes (\mathbf{x}_t^f + \mathbf{x}_t^s + \mathbf{x}_t^t))\\ + \frac{1}{2}\mathbf{h}_{\sigma\sigma}\sigma^2 + \frac{3}{6}\mathbf{h}_{\sigma\sigma\mathbf{x}}\sigma^2(\mathbf{x}_t^f + \mathbf{x}_t^s + \mathbf{x}_t^t) + \frac{1}{6}\mathbf{h}_{\sigma\sigma\sigma}\sigma^3 + \sigma\mathbf{u}_{t+1}\end{aligned}$$

The laws of motion for $\mathbf{x}_t$ that preserve only the first-order, second-order and third-order effects are respectively

$$\begin{aligned}\mathbf{x}_{t+1}^f &= \mathbf{h_x}\mathbf{x}_t^f + \sigma\mathbf{u}_{t+1}\\ \mathbf{x}_{t+1}^s &= \mathbf{h_x}\mathbf{x}_t^s + \frac{1}{2}\mathbf{H_{xx}}(\mathbf{x}_t^f \otimes \mathbf{x}_t^f) + \frac{1}{2}\mathbf{h}_{\sigma\sigma}\sigma^2\\ \mathbf{x}_{t+1}^t &= \mathbf{h_x}\mathbf{x}_t^t + \mathbf{H_{xx}}(\mathbf{x}_t^f \otimes \mathbf{x}_t^s) + \frac{1}{6}\mathbf{H_{xxx}}(\mathbf{x}_t^f \otimes \mathbf{x}_t^f \otimes \mathbf{x}_t^f) + \frac{3}{6}\mathbf{h}_{\sigma\sigma\mathbf{x}}\sigma^2\mathbf{x}_t^f + \frac{1}{6}\mathbf{h}_{\sigma\sigma\sigma}\sigma^3\end{aligned}$$

The state vector under the pruned state-space representation is $\left[(\mathbf{x}_t^f)', (\mathbf{x}_t^s)', (\mathbf{x}_t^t)'\right]'$. As can be seen from the above equations, all terms with higher order effects than the approximation order are dropped. A similar process is followed for deriving the pruned third-order approximation of the policy function.

2.D Additional results

Figure 2.D.1 displays the responses of additional variables to a one-standard-deviation uncertainty shock under the benchmark model and a counterfactual scenario where endogenous job separations are turned off.

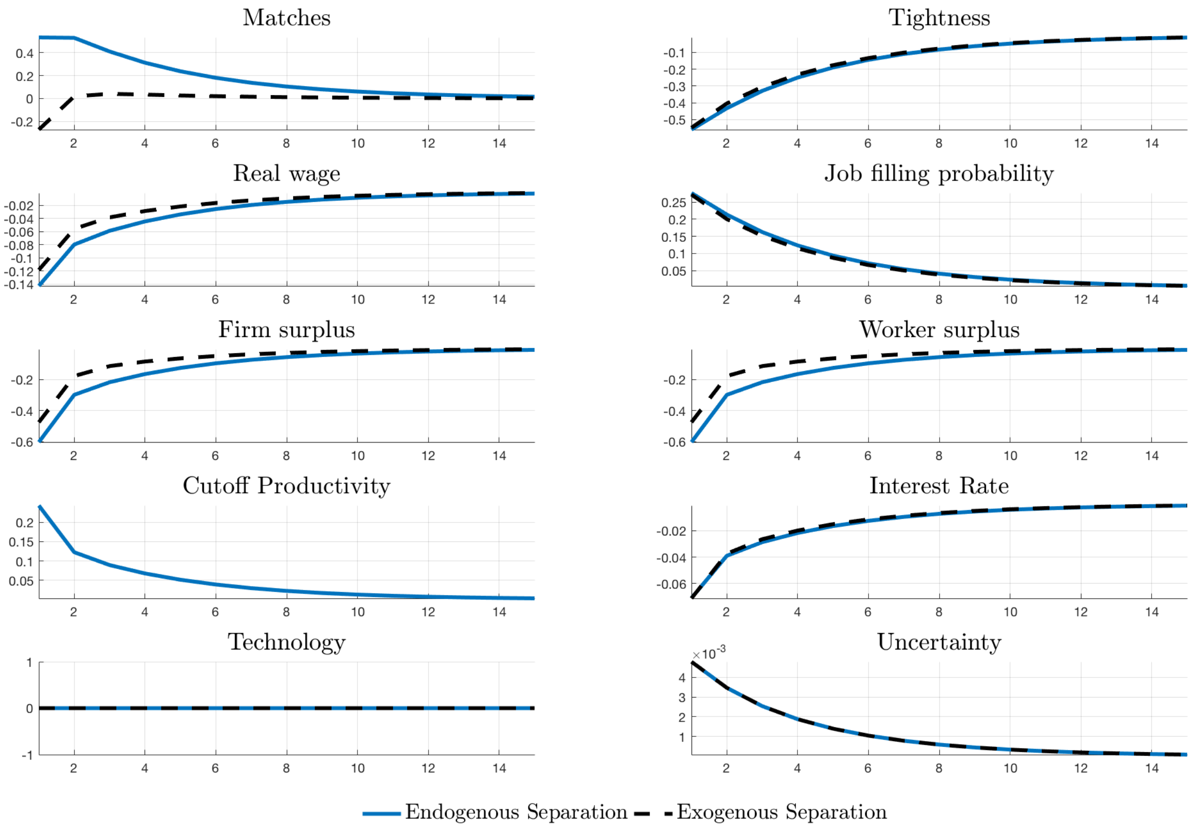

Figure 2.D.1: Impact of uncertainty shock (b)

Note: Impulse Response Functions of Inflation to a one standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state), with the exception of the IRFs of the technology and the uncertainty shocks which are in terms of absolute deviations. The horizontal axis depicts periods in quarters.

Turning to sensitivity analysis, the qualitative effects of uncertainty are robust to different degrees of habit formation, as well as different degrees of price stickiness. As is illustrated in the following experiments, both real frictions, in the form of higher h, as well as nominal frictions, in the form of higher Ω, play an important role for the amplification of uncertainty shocks.

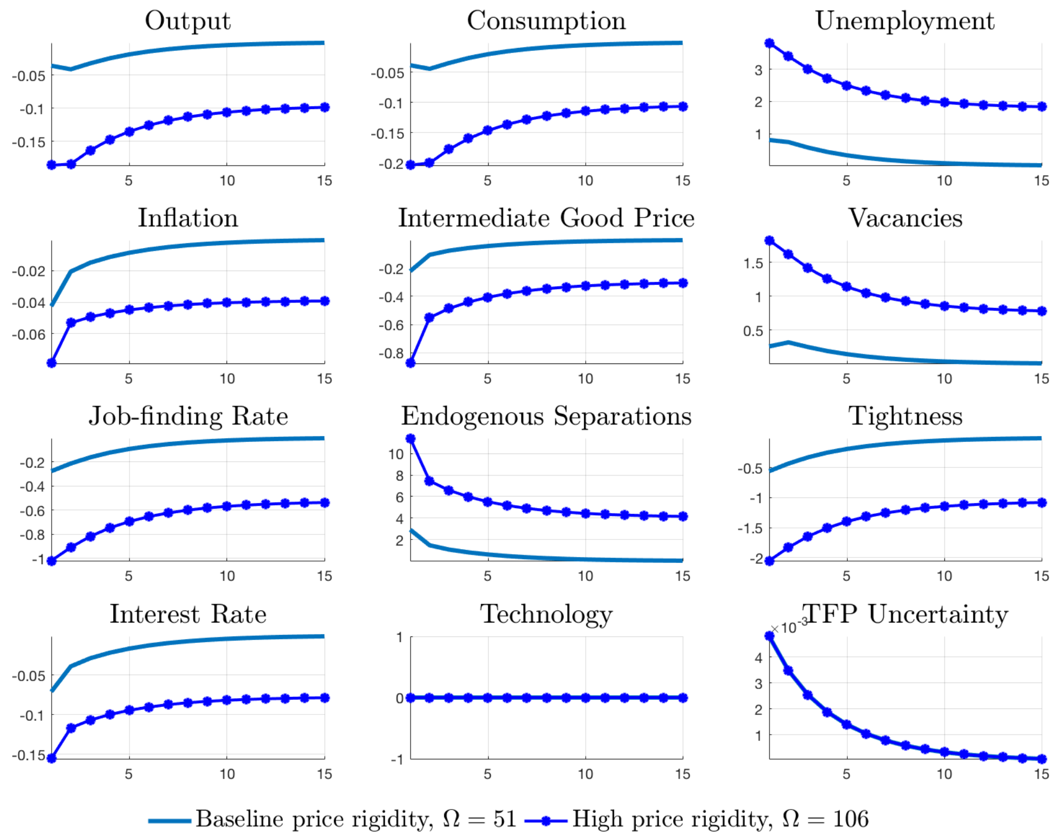

Figure 2.D.2: Sensitivity analysis (a)

Note: Impulse Response Functions of Inflation to a one standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state), with the exception of the IRFs of the technology and the uncertainty shocks which are in terms of absolute deviations. The horizontal axis depicts periods in quarters.

Figure 2.D.2 compares the impulse response functions under the baseline model where $\Omega = 51$ to a model with higher price rigidities where $\Omega = 106$. These values are set such that the slope of the linear NKPC under Rotemberg pricing is the same as the slope of the NKPC in a Calvo pricing model with average price

duration of three and four quarters respectively.[17]

Real frictions such as habits also play an important amplification role as demonstrated in Figure 2.D.3 which compares the impulse response functions under the baseline model, where $h = 0$, with cases of higher degrees of habit formation, $h = 0.2$ and $h = 0.6$.

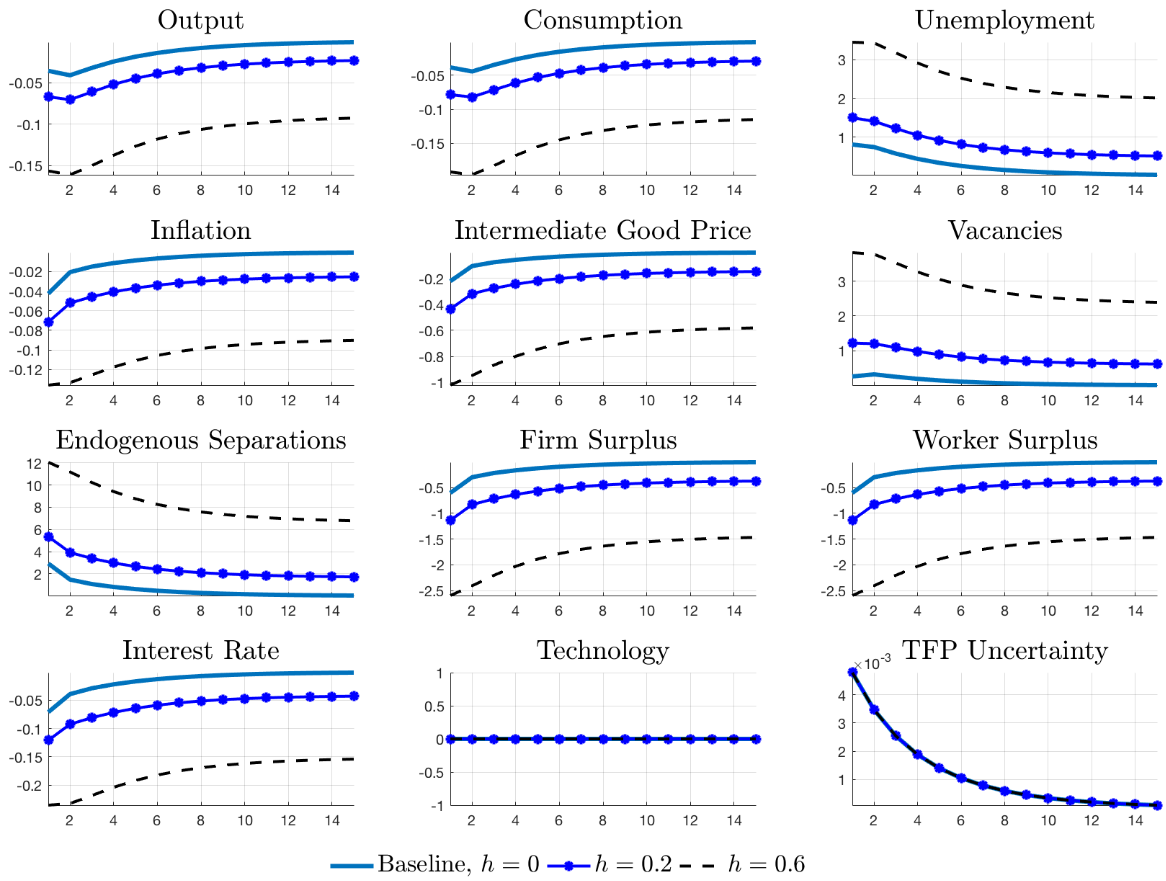

Figure 2.D.3: Sensitivity analysis (b)

Note: Impulse Response Functions of Inflation to a one standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state) process, with the exception of the IRFs of the technology and the uncertainty shocks which are in terms of absolute deviations. The horizontal axis depicts periods in quarters.

[17] To a first order approximation, there is a direct mapping between the two Phillips Curves. The slope under the Calvo NKPC is given by $\frac{(1-\xi)(1-\beta\xi)}{\xi}$, where ξ is the randomly selected share of firms that cannot reset their prices in any given period. The slope under the Rotemberg NKPC is given by $\frac{\eta-1}{\Omega}$. In this exercise I derive Ω for $\xi = 0.66$ and $\xi = 0.75$. We should note that the direct mapping between the two NKPCs does not hold at higher order due to the presence of non-linear terms.

CHAPTER 3

Endogenous producer entry, trade and uncertainty

Abstract In this paper, I examine the macroeconomic impact of uncertainty shocks on firm entry, trade and labor markets. To do so, I build a small open economy model with endogenous producer entry and search and matching frictions. I demonstrate that the precautionary savings behaviour of households propagates the uncertainty shocks through two mechanisms. The first one is the aggregate demand mechanism which is also at play in models with a fixed mass of producers. The second channel arises from the interplay of precautionary behaviour and endogenous producer entry. Precautionary savings from households lead to higher entry of relatively less productive non-trading firms, driving down aggregate productivity and creating inflationary pressures.

3.1 Introduction

This chapter studies the role of firm entry and search frictions for the propagation of macroeconomic uncertainty shocks in open economy models. The analysis takes place through the lens of a dynamic, stochastic, general equilibrium (DSGE) model of international trade and places particular emphasis on the consequences of uncertainty shocks for labor markets, trade and productivity. The model is calibrated to the UK, which has seen a persistent surge in aggregate uncertainty in the recent years, as uncertainty indexes spiked in the aftermath of the Brexit referendum and have remained elevated ever since.[1]

I introduce uncertainty shocks as shocks to the time-varying stochastic volatility of supply and demand type shocks, following Fernandez-Villaverde et al. (2011) and subsequent literature. I build a small open economy New Keynesian model that combines two key building blocks: endogenous firm entry, following Ghironi and Melitz (2005), and the workhorse search-and-matching model with credible bargaining, following Hall and Milgrom (2008).

I depart from models with a fixed size of the tradable sector motivated by the well-documented evidence that entry and product creation account for an important fraction of economic activity fluctuations at business cycle frequencies (Broda and Weinstein, 2010). Instead, this model allows the extensive margin of domestic and exporting activity, namely the number of available varieties in the domestic and export markets, to vary endogenously and to depend on the micro-founded entry decisions of firms.

I also depart from the Nash bargaining specification of wages in order to ad-

[1]News-based measures of uncertainty, such as the UK index of Economic Policy Uncertainty, constructed by Baker et al. (2016), spiked in the years following the 2016 referendum and have remained high. Subjective measures of uncertainty based on firm-level microdata paint a similar picture, with UK businesses reporting that the uncertainty facing their own businesses remains high even five years after the UK's decision to leave the EU (Bloom et al., 2019).

dress Shimer's critique.[2] While there have been numerous remedies suggested[3] several, including Shimer (2005) and Hall (2005), link the low volatility of model-implied unemployment to the excessive responsiveness of real wages. The intuition behind this argument is that real wages are too responsive to underlying shocks which allows workers to extract a large fraction of the match surplus in booms. This limits the incentive of firms to post vacancies and results in a smaller response of the unemployment rate. The alternating offer wage bargaining protocol (henceforth AOB) offers a promising solution to Shimer's puzzle as it generates micro-founded wage rigidity by partially insulating wages from labor market conditions (Hall and Milgrom, 2008). This wage rigidity leads to larger fluctuations of the firm's match surplus and thus stronger incentives for firms to post vacancies and adjust their workforce. I follow Christiano et al. (2016) who embed this wage setting mechanism in a DSGE model and introduce AOB in the labour market block.

A key result that stands out from the analysis is that the precautionary savings behaviour of households propagates the uncertainty shocks through two channels. The first one is the aggregate demand channel which is standard in models with a fixed mass of producers; in response to higher uncertainty prudent households reduce their consumption and increase savings in order to build a buffer wealth stock precautionarily. This leads to lower aggregate demand with contractionary effects for output which are amplified in the presence of search frictions. As lower aggregate demand propagates to the intermediate good sector, firms respond by posting fewer vacancies which leads to higher unemployment. This intensifies the precautionary behaviour of households, and exerts additional negative pressure on aggregate demand and output.

The second channel arises from the interplay of precautionary behaviour and endogenous producer entry. Differently to models with a fixed mass of producers,

[2] As Shimer (2005) shows, the canonical Diamond, Mortensen and Pissarides model with Nash bargaining for wages and standard calibration under-predicts the volatility of unemployment for plausible labour productivity shocks.

[3] To mention a few, Hagedorn and Manovskii (2008) suggest an alternative calibration of the canonical model. Their calibration strategy relies on high labor supply elasticity to deliver the observed volatility in unemployment. However, their calibration falls short in generating plausible values of the worker's outside option as it implies a replacement ratio close to 1 (Costain and Reiter, 2008). Alternative settings include adding (ad-hoc) real wage rigidities (Hall, 2005), and fixed hiring costs (Pissarides, 2009).

precautionary savings also lead to higher firm entry. In the model, lower aggregate demand induces a drop in intermediate good prices which account for part of the sunk entry costs of final producers. As a result domestic firm entry increases and firms with relatively lower idiosyncratic productivity are able to participate in domestic markets. As more non-trading domestic firms enter there is a reduction in the mass of exporters, who face higher competition from non-trading producers for input goods.[4]

The final key result of the analysis is that in more general settings that allow for an endogenously changing size and composition of domestic and exporting producers, uncertainty shocks act like negative aggregate supply shocks. They lead to a lower mean of the firm-level productivity distribution and generate inflationary rather than deflationary pressures. The response of inflation to uncertainty shocks has been the object of academic debate. While some studies find that the negative aggregate demand channel of uncertainty leads to deflationary pressures (see for instance Leduc and Liu (2016) and Basu and Bundick (2017)), others argue that uncertainty shocks generate upward pressures on inflation due to precautionary wage and price setting (Mumtaz and Theodoridis (2015), Born and Pfeifer (2021) and Fasani and Rossi (2018)). This paper contributes to this debate by considering the impact of uncertainty on the firms' self-selection into production and trade and average firm-level productivity.

Uncertainty shocks become relevant in the policy functions of the agents when the model is solved using higher-order perturbations around the steady state (as for first-order approximations, the solution is characterized by "certainty-equivalence"). The model is solved using a third-order Taylor approximation of the policy functions and the laws of motion of state variables around the steady state, following Fernandez-Villaverde et al. (2011), and Born and Pfeifer (2014). Where necessary, "pruning" is used in order to avoid explosive paths and spurious simulations.

[4]As explained in Section 3.3 and described in Cacciatore et al. (2016), this framework is isomorphic to one where firm entry is financed directly via households who own shares in a fully diversified mutual fund of firms. Intuitively, the precautionary motive of households induces households to increase savings via firm equity, leading to lower financing costs for firms and higher firm entry. I find that in both models, regardless of whether firm entry is financed via households buying shares or via firms paying the entry cost in terms of intermediate goods, higher uncertainty leads to higher firm entry.

The rest of this paper is organized in the following way. Section 3.2 reviews related literature. Section 3.3 presents in detail the model features with an emphasis on the wage setting mechanism in the labour market and the process of endogenous producer entry in the goods market. Sections 3.4 and 3.5 analyse the calibration and computational methods used. Section 3.6 presents and discusses the main results and section 3.7 concludes.

3.2 Related literature

This chapter relates to two main strands of research. Firstly, the paper builds on the literature that introduces heterogeneous firms and endogenous producer entry in business cycle models. Following the influential work of Ghironi and Melitz (2005), there has been a growing literature in the intersection of international macroeconomics and international trade that examines how changes in the extensive margin for trade and domestic production matter for aggregate fluctuations. Ghironi and Melitz (2005) find that adding an endogenously varying tradable sector significantly improves the quantitative performance of international RBC models and provides explanations to previous puzzles.[5] In a similar vein, Cacciatore (2014) adopts a setup with endogenous firm entry but departs from Walrasian labour markets. He introduces search frictions and Nash bargaining in a two-country model with endogenous product creation and shows that the labour market structure is crucial for the consequences of trade integration and the degree of business cycle synchronization. The closest paper to this study is Cacciatore and Ghironi (2020), which studies in a similar setup how trade linkages affect the role of monetary policy. Compared to the aforementioned papers, the focus is different here as this chapter investigates how the extensive margin of production and exporting interacts with uncertainty. My analysis contributes to this strand by examining the role of endogenous product creation for the propagation of uncertainty shocks. Additionally, the model improves on previous literature as it features a more realistic labour market block with search frictions and rich microfoundations for rigidity in real wages.

[5] Their model was the first to rationalize the Harrod- Balassa-Samuelson effect.

This chapter is also related to the field of research that studies uncertainty shocks and their implications for aggregate fluctuations. This literature dates back to Bernanke (1980), who highlighted the importance of irreversible investment for uncertainty shocks. It was revived with the influential work of Bloom (2009) who documents evidence that firm-level uncertainty (micro-uncertainty) can account for deep recessions. In subsequent work, Basu and Bundick (2017) study the impact of aggregate uncertainty (macro-uncertainty) and they highlight the precautionary saving channel when agents display prudence. They show that the consequences of aggregate uncertainty for business cycle fluctuations are significant even when accounting for general equilibrium effects, but nominal price rigidities are key to generate empirically plausible co-movements. In the context of open economy models, Fogli and Perri (2015) introduce time-varying macroeconomic uncertainty in an open economy model and study how it affects the accumulation of net foreign assets. They find that precautionary behaviour can partly account for external imbalances, as residents in countries facing higher relative macroeconomic volatility channel their higher savings into foreign assets. Mumtaz and Theodoridis (2015) study a two-country model calibrated to the US and the UK and show that higher uncertainty related to foreign (US) wage mark-up and productivity shocks results in lower UK GDP and higher UK inflation. In a similar manner to the papers mentioned above, I also focus on the precautionary savings mechanism, but emphasize the importance of firm selection and endogenous entry for the transmission of uncertainty and extend this literature by analysing the impact of macroeconomic volatility on the extensive margin of trade and productivity fluctuations.

3.3 Model

I develop a small open economy model which features heterogeneous firms and endogenous producer entry in the goods' market, as in Ghironi and Melitz (2005), and search frictions with credible wage bargaining in the labour market, as in Christiano et al. (2016). The small open economy is modelled as the limiting case of a two country model with the mass of the Home country approaching zero in the limit. As a result of this assumption, the dynamics of the Home country do not impact the rest of the world, and foreign variables are taken as exogenous from the point of view of the Home economy.

The Home country is populated by a continuum of infinitely lived households with identical CRRA preferences. In equilibrium, a fraction of household members is employed and gains a real wage while the remaining members are unemployed and receive an unemployment benefit. On the firms' side, a continuum of multi-product firms produce a final sectoral good which aggregates different product varieties. Each variety is produced by heterogeneous plants characterized by their relative productivity which is drawn from a Pareto distribution. Firms face a sunk cost in order to enter the domestic market and face fixed and per unit costs in order to export. As a result, firms self-select into production and exporting activity, giving rise to an endogenously varying tradable sector.

3.3.1 Households

The members of the representative household derive utility from consuming products of differentiated varieties and they can invest in home and foreign denominated risk-free bonds. They either provide labour and earn a wage or get an unemployment benefit. Following Andolfatto (1996), Merz (1995) and subsequent literature, I assume complete risk-sharing within the household which allows us to abstract from heterogeneity due to changes in the employment status. The representative household maximises the expected intertemporal utility function

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\gamma}}{1-\gamma} \right) , \tag{3.1}$$

where $\mathbb{E}_t$ is the expectation operator conditional on the household's information at time t, $\beta \in (0,1)$ is the subjective discount factor and $\gamma > 0$ is the relative risk aversion. C_t is the consumption basket which aggregates domestic and imported sectoral outputs $C_t(i)$ using a CES technology where foreign and domestic goods enter symmetrically.

The basket is defined as

$$C_t = \left(\int_0^1 C_t(i)^{\frac{\xi-1}{\xi}} di \right)^{\frac{\xi}{\xi-1}} , \tag{3.2}$$

with the associated price index given by

$$P_t = \left(\int_0^1 P_t(i)^{1-\xi} di \right)^{\frac{1}{1-\xi}}, \tag{3.3}$$

where $\xi > 1$ is the elasticity of substitution between sectoral outputs i, and $P_t(i)$ is the sectoral price index. This utility specification implies a 'love-for-variety' effect; a larger set of varieties in the consumption basket implies that the same nominal amount buys more utility. Under this specification, changes in the extensive margin of production matter for welfare and consequently have important implications when comparing the dynamics of model-based variables to the behaviour of their counterparts in the data.

A fraction L_t of household members are employed and receive a real wage w_t while $1 - L_t$ receive the unemployment benefit, ϕ. Households pay lump-sum transfers T_t (which include taxes and intermediation fees from bond portfolio adjustments). I assume that international financial markets are incomplete and households save through nominal risk-free bonds denominated in Home and Foreign currency that are traded internationally. Let B_t and B_t^* denote holdings of Home and Foreign bonds in terms of the Home consumption good.

The known issue of non-stationarity arises in this small open economy model. The steady state level of net foreign asset holdings is not pinned down by the equilibrium conditions, but instead there are multiple steady states depending on the initial conditions of net foreign assets. As a result, temporary shocks can have permanent effects on the level of variables creating a unit-root problem in equilibrium dynamics. The stationarity-inducing technique implemented is the introduction of quadratic portfolio adjustment costs, which are governed by the scale parameter ψ. Following Cacciatore and Ghironi (2020), I assume that households incur a real cost only when buying foreign bonds (which can be thought of as an intermediation fee). This intermediation fee is rebated to households in a lump-sum manner.

The budget constraint in real terms is given by

$$
\begin{aligned}
&B_t + Q_t B_t^* + \frac{\psi}{2} Q_t B_t^{*2} + C_t \\
&\quad = \frac{(1+i_t)B_{t-1}}{\pi_{c,t}} + Q_t \frac{(1+i_t^*)B_{t-1}^*}{\pi_{c,t}^*} + w_t L_t + (1-L_t)\phi + T_t \ ,
\end{aligned}
\tag{3.4}
$$

where $\pi_{c,t} \equiv \frac{P_t}{P_{t-1}}$ denotes the domestic gross inflation rate, and $\pi_{c,t}^*$ the foreign inflation rate.

In each period, the representative household chooses how to optimally allocate resources in consumption and investment solving a utility optimization problem subject to (3.4). The Euler equations for bond holdings are

$$
1 = \mathbb{E}_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left(\frac{1+i_t}{\pi_{c,t+1}} \right) \tag{3.5}
$$

$$
1 + \psi B_t^* = \mathbb{E}_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left(\frac{Q_{t+1}}{Q_t} \right) \left(\frac{1+i_t^*}{\pi_{c,t+1}^*} \right) \tag{3.6}
$$

3.3.2 Labour market

I model the labour market based on the Diamond-Mortensen-Pissarides (DMP) framework and follow closely the specification of Christiano et al. (2016). The core assumption of the DMP framework is that the matching process between workers and firms is costly in terms of time and resources due to matching frictions. These frictions generate positive involuntary unemployment in equilibrium and give rise to a match surplus that agents divide among themselves based on a wage setting specification. Search frictions are captured in a reduced-form way by the matching function $m(u_t, v_t)$, where u_t stands for the number of unemployed searchers and v_t for the number of vacancies. The matching function is increasing in both arguments, concave and homogeneous of degree one

$$
m_t = \mu u_t^{\alpha} v_t^{1-\alpha} \ , \tag{3.7}
$$

where μ captures matching efficiency, and α is the elasticity of matches with respect to the unemployed workers.

I follow the timing convention used in Christiano et al. (2016) and assume that new matches become immediately productive. This timing assumption implies the following law of motion for labour

$$L_t = (\varrho + x_t)\, L_{t-1} \ , \tag{3.8}$$

where $\varrho \in (0, 1)$ is the exogenous survival probability of a match, x_t is the hiring rate, and $x_t L_{t-1}$ is the number of new matches.

Population is normalised to 1. Under the additional full participation assumption, the unemployment rate is given by

$$ur_t = 1 - L_t \ . \tag{3.9}$$

I define two more probabilities that will be useful for the Bellman equations. The job-finding probability is given by the ratio of new matches to the number of searching workers. The latter is the sum of the previously unemployed workers, $1 - L_{t-1}$, and the newly separated ones $(1 - \varrho)L_{t-1}$. The job-finding probability is defined as

$$q_t^u = \frac{x_t L_{t-1}}{1 - \varrho L_{t-1}} \ . \tag{3.10}$$

The counterpart for the firm is the job-filling probability which is the ratio of matches to total vacancies posted:

$$q_t^v = \frac{x_t L_{t-1}}{\bar{v}_t L_{t-1}} \ , \tag{3.11}$$

where $\bar{v}_t$ is the vacancy posting rate.

As the matching function is homogeneous of degree one in its arguments, the labour market can be characterized more compactly by the labour market tightness

$$\theta_t \equiv \frac{\bar{v}_t L_{t-1}}{1 - \varrho L_{t-1}} \ . \tag{3.12}$$

I define below the value functions that enter the match surplus sharing rule. Let $\mathcal{J}_t$ denote the value of a filled vacancy for the firm

$$\mathcal{J}_t = \varphi_t - w_t + \varrho \mathbb{E}_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \mathcal{J}_{t+1} \ , \tag{3.13}$$

where φ_t is the real price of the intermediate good. If a firm successfully fills a vacancy, it obtains a net flow profit in the current period and the continuation value $\mathcal{J}_{t+1}$ adjusted for the probability that the match breaks down.

The value of an unfilled vacancy for the firm is:

$$\mathcal{O}_t = -\kappa + q_t \mathcal{J}_t + (1 - q_t^v)\, \beta\, \mathbb{E}_t \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \mathcal{O}_{t+1} \; . \tag{3.14}$$

A firm that wishes to maintain an unfilled vacancy pays a real vacancy posting cost κ. With probability q_t^v the firm is successful in getting matched and it obtains the asset value $\mathcal{J}_t$. With the complimentary probability the firm fails to fill the vacancy and continues in next period with value $\mathcal{O}_{t+1}$.

There is an unbounded mass of firms so, in equilibrium, the free entry condition implies that the asset value of an open vacancy must be 0, which yields

$$\mathcal{J}_t = \frac{\kappa}{q_t^v} \; . \tag{3.15}$$

Let $\mathcal{V}_t$ denote the value of a match for the worker. The Bellman equation is

$$\mathcal{V}_t = w_t + \mathbb{E}_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left\{ \varrho \mathcal{V}_{t+1} + (1 - \varrho)(q_{t+1}^u \mathcal{V}_{t+1} + (1 - q_{t+1}^u)\, \mathcal{U}_{t+1}) \right\} \; , \tag{3.16}$$

where the first term represents the current gain of the job match, and the final term captures the present discounted continuation value which depends on the survival and job-finding probabilities.

The value of the unemployment state for workers is

$$\mathcal{U}_t = \phi + \mathbb{E}_t \beta \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma} \left\{ (q_{t+1}^u \mathcal{V}_{t+1} + (1 - q_{t+1}^u)\, \mathcal{U}_{t+1}) \right\} \; . \tag{3.17}$$

In the current period, the unemployed worker gains the unemployment benefit ϕ. In the next period, she is successfully matched with a job with probability q_{t+1}^u, in which case she enters period $t+1$ with an asset value $\mathcal{V}_{t+1}$, while with probability $(1 - q_{t+1}^u)$ she remains unemployed and continues in $t+1$ with an asset value $\mathcal{U}_{t+1}$.

Wage setting

An additional surplus sharing equation is required for pinning down wages. Contrary to the majority of search models where wages are the outcome of a Nash bargaining game, I follow Hall and Milgrom (2008) and subsequently Christiano et al. (2016) in assuming that wages are the solution to alternating offer wage bargaining. This wage setting process assumes that workers and firms play a Rubinstein

(1982) game, making sequential wage offers and counteroffers. The core difference between Nash and Rubinstein bargaining lies in the different threat points of the agents, which in turn imply different surplus sharing rules and thus different incentives for firms to post vacancies in response to shocks.

Under Nash bargaining, the threat is to break the bargaining process making the outside option the key variable for the dynamics of the surplus sharing rule. However, under Rubinstein the only credible threat is to delay rather than terminate the bargaining process. The intuition behind this different threat point is that matching between firms and workers generates economic rents in the presence of search costs. As a result, both parties have an incentive to continue bargaining until they agree on the terms of trade instead of dropping out of the process. Bargaining is strategic in the sense that the agents internalize their ability to impose delay costs to the other party when setting wages.

This mechanism has the desirable feature that it brings at a central stage another variable beyond the value of the outside option: the delay costs. The key insight of Hall and Milgrom (2008) is that to the extent that these delay costs are less cyclical than the value of the outside option of the worker the AOB protocol builds persistence in wages. As a result, the elasticity of the net flow value of a match increases and the firms' match value becomes more responsive to underlying shocks. So, firms have a stronger incentive to adjust their workforce following a productivity shock via vacancies and as such, the AOB addresses Shimer's puzzle through micro-founding real wage rigidity.

I follow Christiano et al. (2016) and assume that each period is divided into M subperiods, with workers and firms exchanging wage offers and counteroffers in each subperiod. Agents bargain over the current-period wage, taking future wages as exogenous. The starting offer comes from the firm. There are three possible outcomes of this game: (i) agents continue bargaining until an agreement is reached within the period, in which case the firm incurs a delay cost $\widetilde{\gamma}$ in each subperiod, (ii) agents voluntarily drop out of the bargaining process and (iii) the bargaining breaks down with an exogenous probability ζ.

In this game, the agent's best response is to make the least acceptable offer to the other party. In each odd subperiod, the firm makes the lowest possible wage offer $w^f_{j,t}$ such that the worker is indifferent between dropping out, in which case she receives her outside option, and rejecting the offer with the aim of making a counteroffer next period, in which case she receives the disagreement payoff. I assume that whenever the worker is indifferent between accepting the offer and rejecting it, she accepts. The value of a match to the worker for the odd period j is given by

$$\mathcal{V}^f_{j,t} = \max \left\{ \underbrace{\mathcal{U}_{j,t}}_{\text{Outside Option}}, \underbrace{\zeta\, \mathcal{U}_{j,t} + (1-\zeta)(\frac{\phi}{M} + \mathcal{V}^l_{j+1,t})}_{\text{Disagreement Payoff}} \right\}, \tag{3.18}$$

where the intra-period value of the match for the worker $\mathcal{V}^f_{j,t}$ is given by equation (3.16) when setting wage to $w^f_{j,t}$. The outside option of the worker is

$$\mathcal{U}_{j,t} = \frac{M-j+1}{M}\phi + \mathbb{E}_t\beta\left(\frac{C_{t+1}}{C_t}\right)^{-\gamma}\left\{\left(q^u_{t+1}\mathcal{V}_{t+1} + (1-q^u_{t+1})\,\mathcal{U}_{t+1}\right)\right\}, \tag{3.19}$$

where the term multiplying the unemployment benefit ϕ reflects the fact that the worker receives unemployment benefits proportionally to the subperiods she engages in the negotiation process. The second term in the worker's indifference condition captures the payoff of the worker when she rejects $w^f_{j,t}$ with the intention of making the next subperiod a counteroffer $w^l_{j+1,t}$, which yields an asset value $\mathcal{V}^l_{j+1,t}$.

In each even subperiod, the worker makes the highest possible wage offer $w^l_{j,t}$ such that the firm is indifferent between its outside option and the disagreement payoff

$$\mathcal{J}^l_{j,t} = \max \left\{ \underbrace{0}_{\text{Outside Option}}, \underbrace{\zeta \times 0 + (1-\zeta)(-\widetilde{\gamma} + \mathcal{J}^f_{j+1,t})}_{\text{Disagreement Payoff}} \right\}, \tag{3.20}$$

where $\widetilde{\gamma}$ is the delay cost and $\mathcal{J}^f_{j+1,t}$ is the asset value of the match for the firm once they have made their counteroffer $w^f_{j+1,t}$.

These indifference conditions imply a unique solution to the game. The solution is a sequence of wages $\{w^f_{1,t}, w^l_{2,t}, ..., w^l_{M,t}\}$ derived analytically through backward induction. In the last subperiod M, the best response of the worker is to make a take-it-or leave it offer to the firm, $w^l_{M,t}$, such that $\mathcal{J}^l_{M,t} = 0$. Everything is common knowledge so both parties instantly reach an agreement in subperiod 1. Similarly to the Rubinstein game, there is a unique solution to this game even in the limit case where M goes to infinity.

Under this bargaining protocol, the match surplus sharing rule takes the following form[6]

$$\mathcal{J}_t = \beta_1(\mathcal{V}_t - \mathcal{U}_t) - \beta_2\tilde{\gamma} + \beta_3(\varphi_t - \phi) \ , \tag{3.21}$$

where parameters β_i for $i = 1, 2, 3$ depend on M and ζ.

To provide some intuition for why the AOB protocol leads to higher wage rigidity, it is useful to compare the AOB surplus sharing rule to the sharing rule derived with Nash bargaining. Under Nash bargaining, the value of a match to the firm is proportional to the worker's net match surplus, with the proportionality parameter depending on the bargaining power of workers b: $\mathcal{J}_t = \frac{1-b}{b}(\mathcal{V}_t - \mathcal{U}_t)$. In response to a positive shock, the outside option of the worker rises. To keep $\mathcal{J}_t$ equal to the expected vacancy posting cost so that free entry holds in equilibrium, $\mathcal{V}_t$ must rise as well which demands a large jump in wages.

Under AOB, the weight assigned to the worker's surplus is lower as there are additional (acyclical) forces that drive the dynamics of $\mathcal{J}_t$. As a result, $\mathcal{V}_t$ and w_t don't respond too sensitively to changes in the state of the economy. This bargaining assumption has an advantage over models that impose real wage rigidity through an exogenous parameter (Hall (2005)), as here inertial wages are an equilibrium outcome. It is worth noting that wages are not completely insulated from labour market conditions because for a non-zero probability of negotiation breakdown ζ the outside option $\mathcal{U}_t$ remains relevant for wages.

3.3.3 Production

Following Blanchard and Gali (2010) and subsequent literature, I separate production in two stages to avoid interaction between trade frictions, nominal rigidities and search and matching frictions at the firm level. In the first stage, a continuum of perfectly competitive firms hire labour and produce a homogeneous nontradable intermediate good. This is the stage at which search and matching frictions occur and credible wage bargaining takes place. In the second stage, there is a continuum of monopolistically competitive sectoral producers along the unit interval. Each firm produces a final sectoral good by combining differentiated product

[6]For more details on the surplus sharing rule coefficients see Appendix 3.

varieties (or features) indexed by $\omega \in \Omega_t$. We can think of these sectoral producers as operating an endogenously determined number of plants with each plant producing a variety ω. Plants are ex-ante identical and draw upon entry from a common distribution $G(z)$ their productivity z, which stays fixed thereafter. In equilibrium, because plants face sunk entry costs and fixed exporting costs, only a subset of all available varieties is produced and a subset of those is exported. Therefore, the set of available varieties Ω_t is time-varying. This setup gives rise to selection of firms into production and exporting activity and to an endogenously changing size and composition of the domestic and the tradable sector which is one of the key margins of interest for uncertainty in small open economies.

Intermediate good sector

I assume that production of the homogeneous intermediate good is linear in labour and the production technology for the representative firm follows

$$X_t = Z_t \, L_t \ , \tag{3.22}$$

where X_t denotes the homogeneous good produced by the firm and sold to final producers at a real price φ_t. The state of technology, which is subject to aggregate shocks, is Z_t and L_t is the number of workers successfully matched with the firm.

Final good sector

In the second stage of production, there is a continuum of consumption sectors, i, representing monopolistically competitive firms that produce a sectoral output $Y_t(i)$. I follow Cacciatore and Ghironi (2020) and assume that each final producer aggregates through a CES technology differentiated varieties of the sectoral good which are defined over a continuum Ω_t. These varieties are produced in plants that are heterogeneous in their productivity and use as input the intermediate good that was produced in the previous stage. The sectoral producers are price takers in the input market and they set prices subject to Rotemberg adjustment costs in the final goods market. In every period, they choose how many new varieties to produce and export.

3.3.4 Firm entry

I assume that final producers are symmetric, so i is dropped. The sectoral output, which is sold domestically and abroad, is given by

$$Y_t = \left(\int_{\omega \in \Omega_t} y_t(\omega)^{\frac{\eta-1}{\eta}} d\omega \right)^{\frac{\eta}{\eta-1}} , \tag{3.23}$$

and the production cost associated with the bundle Y_t is

$$P_t^c = \left(\int_{\omega \in \Omega_t} P_t^c(\omega)^{1-\eta} d\omega \right)^{\frac{1}{1-\eta}} , \tag{3.24}$$

where $P_t^c(\omega)$ is the production cost of plant ω in units of domestic currency.

I adopt the Ghironi and Melitz (2005) time-to-build assumption for new entrants and assume that plants exit exogenously with a probability δ.[7] As will be described below, there are no fixed operational production costs when serving the domestic market. New entrants and incumbent plants produce until they are hit by the exit shock. This yields the following law of motion for domestic producers

$$N_{d,t+1} = (1-\delta)\left(N_{d,t} + N_{e,t}\right) . \tag{3.25}$$

The mass of producing plants is a state variable that behaves similarly to the stock of physical capital in a standard RBC setting. To produce a new variety (which we can think of as building a new plant or a new production line), final producers face a sunk start-up cost f_e in units of the intermediate input good or a cost equivalent to $f_e \varphi_t$ in units of consumption. We can interpret this start-up cost as a combination of regulatory and setup costs. The only factor of production is the intermediate good. The technology of a plant with productivity z implies a real marginal cost

$$\varphi_t(z) = \frac{\varphi_t}{z} . \tag{3.26}$$

[7]The assumption of an exogenous exit probability is backed by documented evidence that product destruction displays much less cyclicality than product creation (Broda and Weinstein (2010)). In this setup where plant entry (exit) and product creation (destruction) are conceptually indistinguishable it is also backed by studies showing that plant entry is more cyclical compared to plant exit (Lee and Mukoyama (2008)). For a discussion on the role of endogenous product destruction for business cycle fluctuations and its implication for stabilization policies see Hamano and Zanetti (2017).

Since there are no fixed costs for domestic production, all plants serve domestic consumers and contribute to the production of the final domestic bundle $Y_{d,t}$. However, exporters that contribute to the final exported bundle $Y_{x,t}$, face fixed export costs, equal to $f_x \varphi_t$ in units of consumption, and a per-unit iceberg trade cost $\tau > 1$. Combined, these two costs capture the wasted resources due to tariff and non-tariff trade barriers.

Importantly, the existence of fixed export costs generates the time-varying size of the tradable sector. In the absence of fixed costs, all plants would export and output and prices would be identical across firms. However, fixed export costs imply that only plants with productivity above some endogenous cutoff $z_{x,t}^c$ will find it beneficial to serve the foreign market. Shocks to the productivity or cost components of the firm, which imply changes in the expected profitability of potential exporters, will modify the tradeoff that firms face over their exporting decision. This will result in endogenous fluctuations in the set of exported varieties.

Before analysing the optimality conditions for the final sectoral producers, I define two averages that summarize all relevant information in the productivity distribution of plants for the aggregate variables

$$\widetilde{z}_d \equiv \left(\int_{z_{min}}^{\infty} z^{\eta-1} dG(z) \right)^{\frac{1}{\eta-1}} , \tag{3.27}$$

$$\widetilde{z}_{x,t} \equiv \left(\frac{1}{1-G(z_{x,t}^c)} \int_{z_{x,t}^c}^{\infty} z^{\eta-1} dG(z) \right)^{\frac{1}{\eta-1}} . \tag{3.28}$$

The key aggregation properties of Melitz (2003) hold in this setup, as shown in Ghironi and Melitz (2005). A sector of heterogeneous plants with mass N_d and a productivity distribution $G(z)$ is isomorphic in structure to a sector of N_d identical firms with productivity equal to the weighted average $\widetilde{z}_d$ out of which a fraction $\frac{N_x}{N_d}$ with productivity $\widetilde{z}_x$ export.

I parameterise the productivity distribution to be Pareto with support in $[z_{min}, \infty)$

$$G(z) = 1 - \left(\frac{z}{z_{min}} \right)^{-k} . \tag{3.29}$$

z_{min} is the minimum plant productivity and k is the shape parameter which provides an inverse measure of dispersion. Lower k implies a lower mass of firms close to the minimum productivity level. To have finite higher moments, the condition $k > \eta - 1$ must be satisfied.

The assumption of a Pareto distribution has two key advantages. Firstly, it induces a firm size distribution that is also Pareto, which conforms well with empirical data. Secondly, it simplifies greatly the solution of the model. This is because a variable drawn from a Pareto remains Pareto distributed when truncated from below. Additionally, a Pareto distributed variable has the convenient property that any power function of this variable preserves the Pareto distribution. Under the CES aggregator, firm variables such as real prices, profits and so on are power functions of firm productivity which allows the model to be recast in terms of the two averages defined above.

Under this distributional assumption, the "weighted" productivity averages can be rewritten as

$$\widetilde{z}_d = \left(\frac{k}{k-\eta+1}\right)^{\frac{1}{\eta-1}} z_{min}, \qquad \widetilde{z}_{x,t} = \left(\frac{k}{k-\eta+1}\right)^{\frac{1}{\eta-1}} z^c_{x,t} \, . \tag{3.30}$$

The average firm productivity for the exporters and the Pareto probability density function imply the following relation between exporters and domestic producers

$$N_{x,t} = (1 - G(z^c_{x,t}))N_{d,t} = \left(\frac{\widetilde{z}_{x,t}}{z_{min}}\right)^{-k} \left(\frac{k}{k-\eta+1}\right)^{\frac{k}{\eta-1}} \, . \tag{3.31}$$

Production can be decomposed in two output bundles, $Y_{d,t}$ and $Y_{x,t}$, for domestic sales and for exporting. Changing variables and recasting (3.23) so that final producers aggregate over the productivity distribution instead of the set of varieties yields

$$Y_{d,t} = \left(\int_{z_{min}}^{\infty} y_t(z)^{\frac{\eta-1}{\eta}} N_{d,t} dG(z)\right)^{\frac{\eta}{\eta-1}}, \quad Y_{x,t} = \left(\frac{1}{1-G(z^c_{x,t})}\int_{z^c_{x,t},}^{\infty} y_t(z)^{\frac{\eta-1}{\eta}} N_{x,t} dG(z)\right)^{\frac{\eta}{\eta-1}} . \tag{3.32}$$

The associated production cost indexes in terms of the Home consumption good are

$$\frac{P^c_{d,t}}{P_t} = \left(\int_{z_{min}}^{\infty} p^c_t(z)^{1-\eta} N_{d,t} dG(z) \right)^{\frac{1}{1-\eta}} = N_{d,t}^{\frac{1}{\eta-1}} \frac{\varphi_t}{\tilde{z}_d} \, , \tag{3.33}$$

$$\frac{P^c_{x,t}}{P_t} = \left(\frac{1}{1-G(z^c_{x,t})} \int_{z^c_{x,t},}^{\infty} p^c_t(z)^{1-\eta} N_{x,t} dG(z) \right)^{\frac{1}{1-\eta}} = N_{x,t}^{\frac{1}{\eta-1}} \frac{\varphi_t}{\tilde{z}_{x,t}} \tag{3.34}$$

where the second equality takes into account (3.26) as well as (3.27) and (3.28).

Final producers choose in every period how many new varieties $N_{e,t}$ (or equivalently $N_{d,t+1}$) to create for domestic sales and how many varieties $N_{x,t}$ to include in the export bundle in order to minimize their cost function[8]

$$\mathbb{E}_t \sum_{s=t}^{\infty} \beta_{t,t+s} \left(\frac{P^c_{d,s}}{P_s} Y_{d,s} + \tau \frac{P^c_{x,s}}{P_s} Y_{x,s} + N_{e,s} f_e \varphi_s + N_{x,s} f_x \varphi_s \right) \, , \tag{3.35}$$

where $\beta_{t,t+s} = (\beta(1-\delta))^s \left(\frac{C_{t+s}}{C_t}\right)^{-\gamma}$ is the stochastic discount factor of firms. Even though firms are owned by households and share the same discount factor, they factor in the probability of exit which may occur prior to production due to the time-to-build assumption.

Producers take the residual demand for their output bundles $Y_{d,t}$ and $Y_{x,t}$ as given and minimize expected discounted costs subject to their production technology constraint, which implies real marginal costs as in (3.33) and (3.34), the Pareto productivity distribution of plants taking (3.28) and (3.31) as constraints and subject to the law of motion of producers (3.25).

The first order condition with respect to $N_{d,t+1}$ is

$$\varphi_t f_e = \mathbb{E}_t \beta_{t,t+1} \left\{ \varphi_{t+1} (f_e - \frac{N_{x,t+1}}{N_{d,t+1}} f_x) + \frac{1}{\eta - 1} \left(\frac{P^c_{d,t+1}}{P_{t+1}} \frac{Y_{d,t+1}}{N_{d,t+1}} + \tau \frac{P^c_{x,t+1}}{P_{t+1}} \frac{Y_{x,t+1}}{N_{x,t+1}} \frac{N_{x,t+1}}{N_{d,t+1}} \right) \right\} \tag{3.36}$$

[8]Note that differently to Ghironi and Melitz (2005), in this setup the relevant profit maximizing unit is the final sectoral producer. As a result, product creation lies with the "investment" decision of final sectoral producers and the entry costs $f_e \varphi_t$ correspond to the endogenously fluctuating price of their investment. In the Ghironi and Melitz (2005) framework, product creation is determined by a free entry condition for plants combined with the Euler equation for shares that governs the investment decision of households in firm equity. However, as discussed in Cacciatore and Ghironi (2020), under the assumption that the final producer's elasticity of substitution across varieties η is the same as the household's elasticity of substitution across sectoral goods ξ, the two models are isomorphic.

This condition states that at the optimum the sunk cost incurred by the final producer in order to create a new variety, $\varphi_t f_e$, is equal to the present discounted value of the marginal benefit of variety creation. The latter is equal to the expected discounted cost that is saved from future entry investments plus the future marginal revenue from the contribution of the variety to the domestic bundle. The final producer also factors in the additional revenue in case the variety is added to the exported bundle net of the fixed exporting costs, which occurs with probability $\frac{N_x}{N_d}$.

The first order condition with respect to $N_{x,t}$ yields

$$\frac{1}{\eta-1}\frac{P^c_{x,t}}{P_t}\frac{Y_{x,t}}{N_{x,t}}\tau = \frac{k}{k-\eta+1} f_x \varphi_t \ . \tag{3.37}$$

The above optimality condition states that, in equilibrium, the marginal revenue from adding a variety with the cutoff productivity $z^c_{x,t}$ to the export bundle is equal to the fixed exporting cost. Equation (3.37) is equivalent to the zero profit condition for exporters in Ghironi and Melitz (2005). It determines the set of exporters which endogenously fluctuates over time, as only plants with productivity above the cutoff level $z^c_{x,t}$ will opt to serve the foreign market.

Price setting

In the absence of fixed costs, firms would set one price. An arbitrage condition adjusted for iceberg costs would map this into the export price in terms of the foreign currency. However, the existence of fixed export costs implies that the composition of the domestic and export bundles differ, and so producers set two different prices. Under producer currency pricing, they choose $\rho_{d,t} = \frac{P_{d,y}}{P_t}$ and $\rho^h_{x,t} = \frac{P^h_{x,t}}{P_t}$ in order to maximise the present discounted value of the stream of dividends

$$\begin{aligned} d_t = \mathbb{E}_t\beta_{t,t+1}\left(\rho_{d,t}(1-\tfrac{\Xi}{2}(\tfrac{P_{d,t}}{P_{d,t-1}}-1)^2)Y_{d,t} - \varphi_{d,t}Y_{d,t}\right) + \\ \mathbb{E}_t\beta_{t,t+1}\left(\rho^h_{x,t}(1-\tfrac{\Xi}{2}(\tfrac{P^h_{x,t}}{P^h_{x,t-1}}-1)^2)Y_{x,t} - \tau\varphi_{x,t}Y_{x,t}\right) - \varphi N_{e,t}f_e - \varphi N_{x,t}f_x \end{aligned} \tag{3.38}$$

Producers take the demand schedules for the domestic and exported bundle as given

$$Y_{d,t} = \left(\frac{P_{d,t}}{P_t}\right)^{-\xi} Y_t \qquad\qquad Y_{x,t} = \left(\frac{P_{x,t}}{P^*_t}\right)^{-\xi} Y^*_t \ . \tag{3.39}$$

I defer the derivation of the first order conditions on $\rho_{d,t}$ and $\rho^h_{x,t}$ to Appendix 3, and note that optimal price setting yields

$$\rho_{d,t} = \mu_{d,t} N_{d,t}^{\frac{1}{1-\eta}} \frac{\varphi}{\tilde{z}_{d,t}} \qquad \rho^h_{x,t} = \tau \mu_{x,t} N_{x,t}^{\frac{1}{1-\eta}} \frac{\varphi}{\tilde{z}_{x,t}} \ . \tag{3.40}$$

Under flexible prices, the markups $\mu_{d,t}$ and $\mu_{x,t}$ would be constant and equal to $\frac{\eta}{\eta-1}$. Using the law of one price, $P^h_{x,t} = \mathcal{E}_t P_{x,t}$, the FOCs on the optimal price of exporters can be rewritten as

$$\rho_{x,t} \equiv \frac{P_{x,t}}{P^*_t} = \frac{\tau}{Q_t} \mu_{x,t} N_{x,t}^{\frac{1}{1-\eta}} \frac{\varphi}{\tilde{z}_{x,t}} \ , \tag{3.41}$$

where $\mathcal{E}_t$ denotes the nominal exchange rate and $Q_t = \frac{\mathcal{E}_t P^*_t}{P_t}$ is the *welfare-consistent* real exchange rate. I also define the average real price for domestic and exported varieties as following

$$\tilde{\rho}_{d,t} \equiv N_{d,t}^{\frac{1}{\eta-1}} \rho_{d,t} = \mu_{d,t} \frac{\varphi}{\tilde{z}_{d,t}} \qquad \tilde{\rho}_{x,t} \equiv N_{x,t}^{\frac{1}{\eta-1}} \rho_{x,t} = \frac{\tau}{Q_t} \mu_{x,t} \frac{\varphi}{\tilde{z}_{x,t}} \tag{3.42}$$

Finally, I define the amount of the average plant that is contributed to the domestic and exported bundles

$$\tilde{y}_{d,t} \equiv \tilde{\rho}_{d,t}^{-\xi} Y_t \qquad \tilde{y}_{x,t} \equiv \tilde{\rho}_{x,t}^{-\xi} Y^*_t \ . \tag{3.43}$$

The above imply the following equilibrium condition on prices

$$1 = N_{d,t} \tilde{\rho}_{d,t}^{1-\eta} + N_{x,t} {\tilde{\rho}^*_{x,t}}^{1-\eta} \ . \tag{3.44}$$

3.3.5 Market clearing and net foreign assets

In equilibrium, the markets for the intermediate good clear which implies

$$Z_t L_t = N_{d,t} \frac{\tilde{y}_{d,t}}{\tilde{z}_d} + \tau N_{x,t} \frac{\tilde{y}_{x,t}}{\tilde{z}_{x,t}} + N_{e,t} f_e + N_{x,t} f_x \ . \tag{3.45}$$

The sunk entry and fixed exporting costs absorb real resources which become unavailable for the production of consumption goods. The model therefore resembles a two-sector setup where labour demand is divided in demand for productive purposes and for investment purposes. Labour productivity is defined as total output over the sum of labour used in both productive and investment purposes (i.e., labour used to pay the entry costs of domestic production and the fixed costs of exporting). Note that labour markets do not clear due to search frictions which results in positive involuntary equilibrium unemployment.

Market clearing for the final consumption good yields

$$Y_t = C_t - \kappa V_t - \frac{\Xi}{2}(\pi_{d,t} - 1)^2 Y_t - \frac{\Xi}{2}(\pi^h_{x,t} - 1)^2 Y_t \ . \tag{3.46}$$

To close the model I derive the law of motion of the net foreign asset holdings for the Home economy. Imposing that in equilibrium domestic bonds are in zero net supply and aggregating over the individual budget constraints at home yields

$$Q_t B^*_t = \frac{(1 + i^*_t)}{\pi^*_t} Q_t B^*_{t-1} + TB_t \ , \tag{3.47}$$

where the trade balance is defined as the difference in the value of exports and imports; $TB_t = Q_t N_{x,t}\tilde{\rho}_{x,t}\tilde{y}_{x,t} - N^*_{x,t}\tilde{\rho}^*_{x,t}\tilde{y}^*_{x,t}$. In the absence of international bond trading the above equations implies that trade is balanced in equilibrium, $TB_t = 0$.

3.3.6 Welfare consistent variables

One issue highlighted in Ghironi and Melitz (2005) and Cacciatore and Ghironi (2020) is the comparability between model-implied variables and their counterparts in the data. Model variables are welfare-consistent in the sense that they reflect the changes in welfare due to fluctuations in product variety. For instance, a change in the price index in (3.44) captures both changes in the average prices of the domestic producer and foreign exporter, as well as changes in the range of available goods at the Home economy. In contrast, most data-relevant series (e.g., CPI) do not reflect the same variety-changing effects, which are harder to measure as they are sensitive to our choice of the utility functional form and the time frequency considered.

This is particularly relevant for the monetary policy authority that sets their policy rule based on data-consistent series. To that aim, I modify the price deflator in order to control for variety effects. The adjusted price index is given by

$$\hat{P}_t = (N_{d,t} + N^*_{x,t})^{\frac{1}{\eta-1}} P_t \ , \tag{3.48}$$

where the first term captures product variety at Home. The data-consistent real variables are then the nominal variables divided with the appropriate deflator $\hat{P}_t$.

For instance, the data-consistent real exchange rate is

$$\hat{Q}_t \equiv \mathcal{E}_t \frac{\hat{P}_t^*}{\hat{P}_t} \ , \tag{3.49}$$

where $\mathrm{E}_t isthenominalexchangerate.$

Monetary policy

I assume that the central bank sets interest rates based on the following Taylor-type rule

$$1 + i_t = \left((1 + i^{ss}) \left(\frac{\hat{\pi}_{c,t}}{\hat{\bar{\pi}}} \right)^{\phi_\pi} \left(\frac{\hat{Y}_t}{\hat{\bar{Y}}} \right)^{\phi_y} \right)^{1-\phi_i} i_{t-1}^{\phi_i} \ , \tag{3.50}$$

where i_t is the nominal interest rate and i^{ss} is its steady-state value. The monetary authority responds to changes in the data-consistent inflation $\hat{\pi}_{c,t} \equiv \frac{\hat{P}_t}{\hat{P}_{t-1}}$ and output $\hat{Y}_t \equiv \frac{Y_t P_t}{\hat{P}_t}$ from their targets values $\hat{\bar{\pi}}$ and $\hat{\bar{Y}}$ respectively. The response coefficients ϕ_π and ϕ_y control the strength of the central bank's responses to these deviations. The parameter ϕ_i captures the central bank's preferences for smoothing policy.

Fiscal policy

Finally, the government plays a very limited role in the economy. The government balances its budget in every period and is restricted to transfers in the form of unemployment benefits which are financed through lump-sum taxes.

3.3.7 Exogenous processes

Similarly to Chapter 2, I assume that the TFP shock Z_t follows a first-order Markov process

$$\ln Z_t = (1 - \rho_z) \ln Z + \rho_z \ln Z_{t-1} + \sigma_t \epsilon_t \ , \tag{3.51}$$

where $\rho_z \in (0, 1)$ captures the persistence of the technology shock. The innovation term ϵ_t, also called first-moment shock, is a random variable following an i.i.d. standard normal distribution. The term σ_t is the standard deviation of ϵ_t.

I follow Fernandez-Villaverde et al. (2011) and introduce uncertainty into the model by assuming that the standard deviation of ϵ_t is not constant but time-varying, following a first-order Markov process

$$\ln \sigma_t = (1 - \rho_\sigma) \ln \sigma + \rho_\sigma \ln(\sigma_{t-1}) + \eta_\sigma \epsilon_t^\sigma \ , \tag{3.52}$$

where the parameter $\rho_\sigma \in (0, 1)$ captures the persistence of the uncertainty shock. The innovation term ϵ_t^σ, also called a second-moment shock, is a random variable following an i.i.d. standard normal distribution. The uncertainty shock ϵ_t^σ is a mean-preserving shock, which implies that it does not shift the level of aggregate technology and thus does not change the fundamentals of the model but only increases the variance of the distribution of ϵ_t.

3.4 Calibration

I calibrate the model in quarterly frequencies. For conventional parameters, I use values that are standard in the literature. For less conventional parameters I calibrate the model to match targets of the UK economy prior to Brexit. When not possible to use UK targets I follow the calibration strategy of Ghironi and Melitz (2005). Table 3.B.1 summarizes the calibrated values of the model parameters.

Preferences. The subjective discount factor is set to $\beta = 0.995$ so that the model is consistent with a long-run annual real interest rate of 2%. The relative risk aversion coefficient is set to $\gamma = 2$. The elasticity of substitution among differentiated goods for both plants and final producers, η and ξ, is set to 3.8 following Ghironi and Melitz (2005). The intermediation cost for adjusting portfolio holdings is equal to $\psi = 0.0025$ as in Schmitt-Grohe and Uribe (2003).

Production. The exogenous firm exit shock δ is set to 0.026, to match ONS data on the UK annual business death rate (10.5%). The minimum productivity level z_{min} is normalized to 1. The scale parameter for the sunk entry costs f_e is also set to 1, as what matters for the exporting decision of firms is the ratio $\frac{f_e}{f_x}$ and a change in f_e corresponds to a change in the unit of measure for output and mass of producers. The scale parameter for exporting costs f_x is calibrated to match the steady state proportion of UK businesses that engage in international trade which is 15%. I set the iceberg cost τ to 1.5 which is consistent with the trade-weighted average of bilateral trade costs for UK reported in Novy (2006). I set the shape parameter of the Pareto distribution to k to 3.4 as in Ghironi and Melitz (2005). Finally, the parameter that governs the degree of price stickiness, Ξ, is set to 80 as in Cacciatore and Ghironi (2020).

Labour Market. The elasticity of job matches with respect to searching workers is set to $\epsilon = 0.5$, as in Blanchard and Gali (2010). I set the survival rate to $\rho = 0.95$ in line with UK estimates on separation rates. The number of bargaining rounds is set to $M = 60$, which corresponds to the number of working days per quarter, following Christiano et al. (2016). I calibrate the unemployment benefit ϕ to match a steady state replacement ratio of 0.4, which is close to the value reported by Nickell (1997). The labour market parameters remaining to be calibrated are the efficiency of the matching function μ, the real vacancy posting cost κ, the delay costs $\tilde{\gamma}$ and the probability of negotiation breakdown ζ. I calibrate κ so that in steady state the total vacancy posting costs equal 1% of the steady state output. I calibrate $\tilde{\gamma}$ and μ by targeting a post-hiring steady-state unemployment rate of $U = 5\%$ and a steady-state job filling probability of $q^v = 0.7$. This calibration strategy yields $\mu = 0.58$, $\kappa = 0.68$ and $\tilde{\gamma} = 0.02$. Finally, I calibrate the probability of an exogenous breakup in negotiations ζ to match a 2% probability of breakdown in each renegotiation round following Christiano et al. (2016). Sensitivity analysis results regarding different values of ζ are presented in Appendix 3.

Exogenous Shock Processes and Monetary Policy. I calibrate the exogenous processes following Leduc and Liu (2016). Specifically, I parameterise the level process of TFP to standard values in the RBC literature (setting $\rho_z = 0.98$ and $\sigma = 0.01$), I set the persistence parameter of the volatility process to $\rho_\sigma = 0.76$, and the steady state standard deviation of the volatility shock to $\eta_\sigma = 0.392$. In the baseline model, I abstract from smoothing in the monetary policy rule (setting $\phi_i = 0$) and set the Taylor Rule coefficients to conventional values in the literature: $\phi_\pi = 1.5$, $\phi_y = 0.2$.

3.5 Solution

Uncertainty is introduced as a second-moment shock. Specifically, I firstly introduce uncertainty as a shock to the time-varying volatility of the aggregate TFP process, which proxies supply-side shocks. Secondly, I introduce uncertainty as a shock to the time-varying volatility of the household's discount factor, which proxies demand-type shocks.

I solve the model using third-order Taylor approximations. Under a first-order approximation, the model solution is characterized by the certainty equivalence property. In other words, by solving the model via first-order Taylor polynomials we impose that the solution in the stochastic model, where agents know only the distribution of future shocks, is equivalent to the solution of the deterministic model, where agents know not only the distribution but the exact realizations of future shocks. As a result of certainty equivalence, under a first-order approximation only first moment shocks enter the decision rule of the agents and higher moments of the shock distribution are omitted.

In a second-order approximation, uncertainty enters the policy functions but only indirectly as the product of first-moment and second-moment innovations and thus cannot be studied separately (Fernandez-Villaverde et al., 2011). Therefore, we require the model to be solved using third-order Taylor polynomials in order to isolate the effect of uncertainty shocks.

In order to compute the GIRFs of the endogenous variables to an uncertainty shock, I follow the algorithm described by Fernandez-Villaverde et al. (2011) and Born and Pfeifer (2014).[9] In the following quantitative experiments, the GIRFs are based on deviations from the ergodic mean on the variables (also defined as the stochastic steady state), following a one-time, persistent, four-standard-deviations uncertainty shock ϵ_t^{σ} in the first period. Due to the instability of the approximated solution, we impose pruning, dropping the higher-order terms that generate unstable dynamics and replacing them with lower-order terms.[10]

[9] The algorithm followed is described in detail in Section 2.5 of Chapter 2, to which I refer the reader.

[10] For a detailed analysis on pruning see Appendix 2 in Section 2.C.

3.6 Quantitative analysis

In this section, I investigate the dynamic response of the economy to uncertainty shocks. I examine the impulse response functions of key endogenous variables to a one-time, four-standard-deviation uncertainty shock to the TFP process.[11] In Appendix 3, I also examine the responses of key variables to uncertainty specified as a persistent shock to the stochastic volatility of the household's discount factor which proxies for demand-type shocks, and I demonstrate that responses are qualitatively similar between the two experiments. Here I focus particularly on the impact of uncertainty on firm dynamics, aggregate productivity and labour markets.

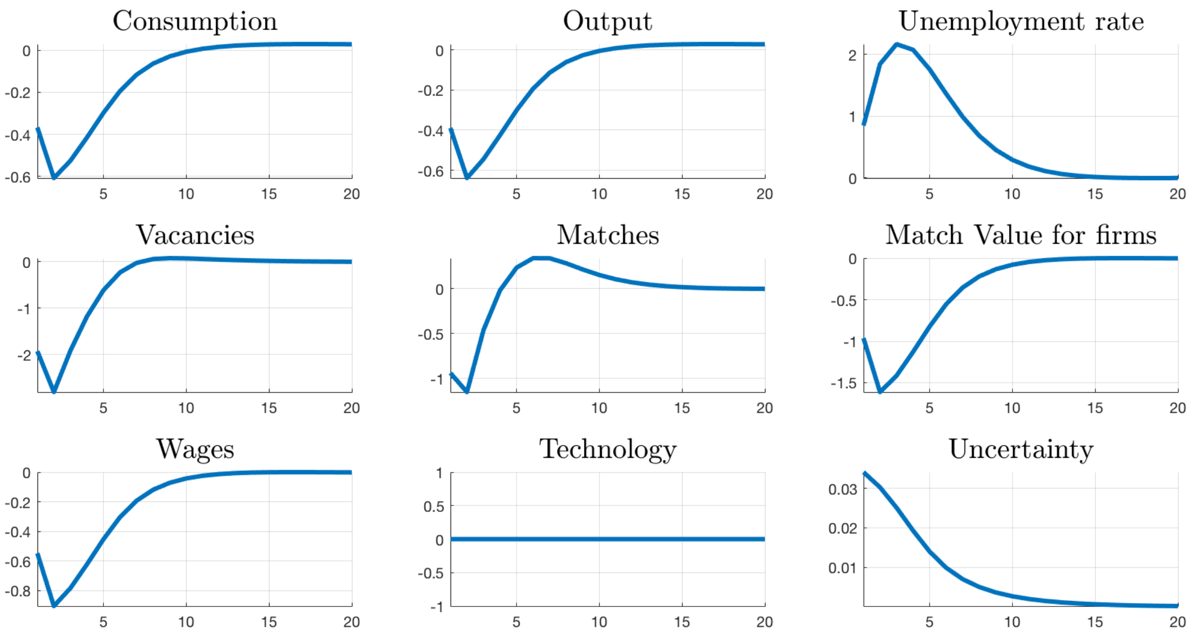

Figure 3.1: Impact of uncertainty shock (a)

Note: Impulse Response Functions to a four standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state) apart from the responses of technology and uncertainty shocks which are in absolute deviations from steady state. The horizontal axis depicts periods in quarters.

In response to higher uncertainty, agents have a precautionary saving motive; they increase their savings and postpone consumption leading to a drop in aggregate demand. This precautionary behaviour of households explains the reduction

[11] I consider a four-standard-deviation shock to capture the magnitude of the effect of the Brexit referendum on the Economic Policy Uncertainty (EPU) index.

in consumption and output on impact. The decline in aggregate demand propagates to the input good sector and leads to a lower relative price of the input goods, φ. Due to lower expected profits the value of a new job match, $\mathcal{J}$, falls as well. Firms react to the decrease in the match value by posting fewer vacancies, and as jobs become harder to find the unemployment rate increases. This in turn leads the household income to decrease further and compounds the initial drop in aggregate demand. So far the standard precautionary savings channel is at play, amplifying the effects of the uncertainty shock through search frictions.[12]

In a model with an exogenously fixed distribution of firm-level productivity, the dynamics of labour productivity would have been pinned down by the response of the TFP (assuming a production technology which is linear in labour as in our framework) and would remain unaffected by the mean-preserving uncertainty shock. However, in a more general framework that allows the firm-level distribution to endogenously change through shifts in the cut-off productivity levels of firms, the labour productivity of the small open economy is negatively impacted by the uncertainty shock.

As Figure 3.2 shows, this is directly linked with the response of entrant firms and the shift in the productivity distribution average. Uncertainty over the productivity of workers affects the sunk entry costs as well as the variable and fixed production costs of domestic producers which are functions of φ. Potential entrants face lower costs of entry φf_e which allows less productive firms, that would otherwise find it unprofitable to pay the sunk costs, to enter the domestic market. This leads to a sharp decrease in the average firm productivity, $\tilde{z}$ and a gradual build up of mass of domestic producers N_d. As the impact of the uncertainty shock dissipates and φ_t and entry costs return to their steady state values, new firms are deterred from entering the market to replace firms that are hit by the exogenous exit shock. The mass of producers falls back and the average firm-level productivity reverts to its ergodic mean value. The decline in output per producer, $\tilde{y}_d$ reconciles the positive entry following the uncertainty shock with lower aggregate output.

[12] For a discussion on the role of labour market rigidites for the propagation of uncertainty shocks, see Leduc and Liu (2016) as well as Sections 2.6 and 2.7 in Chapter 2.

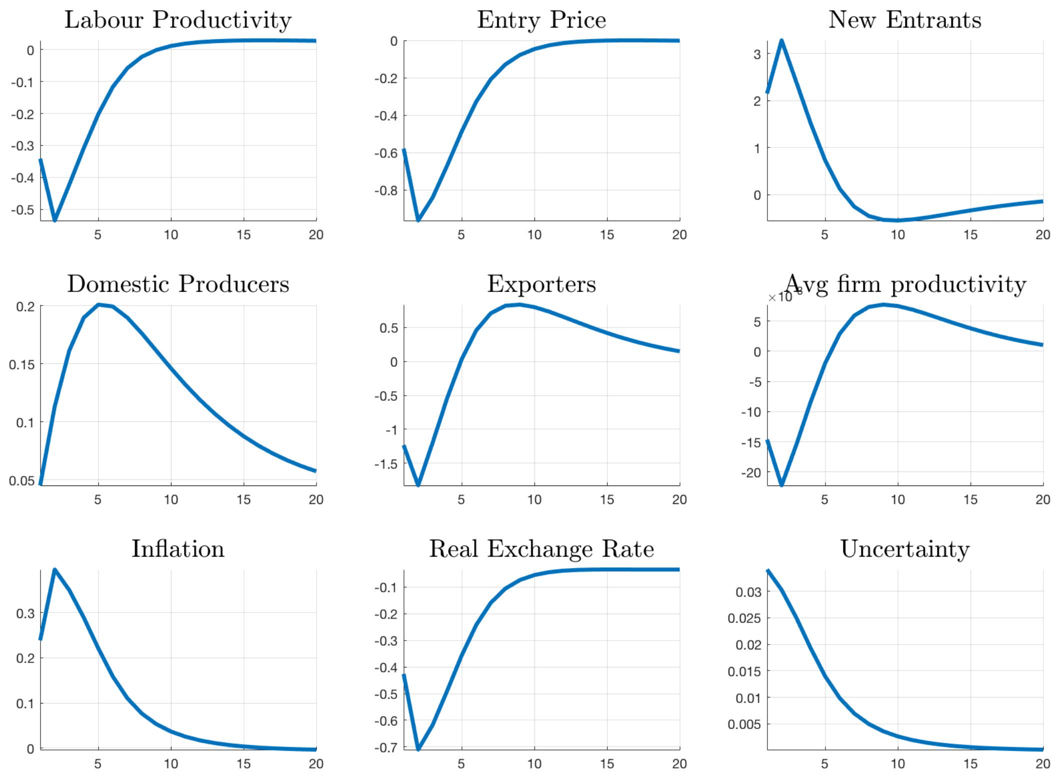

Figure 3.2: Impact of uncertainty shock (b)

Note: Impulse Response Functions to a four standard deviation uncertainty shock to the technology process. All IRFs are in terms of % deviations from the ergodic mean (stochastic steady state) apart from the responses of technology and uncertainty shocks which are in absolute deviations from steady state. The horizontal axis depicts periods in quarters.

Exporters face increased competition for the intermediate input good from the non-trading domestic firms, which is reflected in the dynamics of the average exporter productivity level $\tilde{z}_x$. Due to increased domestic competition, a higher cut-off productivity $\tilde{z}_x^c$ is required for exporting to be profitable. This shifts $\tilde{z}_x$ upwards, and leads to a decrease in the mass of exporters N_x.

The decline of the average firm-level productivity and labour productivity due to higher firm entry of less productive firms, acts in a similar way as a negative TFP shock, pushing CPI inflation up and leading to an appreciation of the real exchange rate as shown in Figure 3.2. This result shows that in frameworks were the assumption of having a fixed distribution of firm-level productivity and a fixed mass of producers is relaxed, uncertainty shocks can have inflationary rather than deflationary effects, a result that goes against the key finding of the seminal paper of Leduc and Liu (2016).

Before continuing the analysis I should note that the model structure does not allow for wait-and-see effects of uncertainty. This is the case in various setups that abstract from idiosyncratic firm-level uncertainty and focus instead on the impact of aggregate uncertainty in models where the free entry condition for firms holds. In this framework, even though final producers commit resources to irreversible projects, as they face sunk entry costs, the value of the option to wait is zero due to the free entry assumption and the fact that the aggregate uncertainty shock and the exit probability are common across firms. As a result, the real-option-to-wait mechanism is muted, and the responses of entrants and exporters are governed by the precautionary behaviour of households.[13]

To gain some intuition over our results, I find it useful to draw a parallel between the effects of uncertainty in this framework and the impact of uncertainty shocks in a model with homogeneous firms and capital. Uncertainty in a standard model can be (counterfactually) expansionary as the precautionary savings motive of households leads to an increase in investment (Basu and Bundick, 2017). In a framework with heterogeneous firms and endogenous producer entry, the mass of producers, which is a state variable, displays a similar dynamic response to that of capital in the standard representative firm model. Precautionary savings behaviour leads to an increase in plant "investment" defined as $I_t = N_{e,t} f_e \varphi_t$. This result holds under both sticky and flexible prices as the next subsection highlights.

The role of wage stickiness

Here, I explore the role of wage inertia by comparing the baseline model in which wages are determined by alternating offers bargaining, to a model where workers and firms follow Nash bargaining. For comparability reasons, in the second version of the model, the targeted moments and all equilibrium conditions are kept unchanged, but I modify the surplus sharing rule. This is straightforward to do as the AOB sharing rule nests NB by setting the parameters in equation (3.21) equal

[13] As shown in Bilbiie et al. (2012) if I denote with $\tilde{\mathcal{O}}_t$ the final producer's option value to wait and $\tilde{\mathcal{E}}_t$ their value of entry then the option value to wait is given by $\tilde{\mathcal{O}}_t = \max\left(\tilde{\mathcal{E}}_t, \beta\tilde{\mathcal{O}}_{t+1}\right)$. These values are the same across firms as prior to entry all firms are identical. The free entry condition drives the term $\tilde{\mathcal{E}}_t$ to zero in every period, and thus $\tilde{\mathcal{O}}_t = \beta\tilde{\mathcal{O}}_{t+1} \forall t$. Due to discounting $\beta^T \tilde{\mathcal{O}}_{t+T}$ approaches 0 in the limit as $T \to \infty$ which implies that $\tilde{\mathcal{O}}_t = 0$ as a stable solution.

to

$$\beta_1 = \frac{1-b}{b} \text{ and } \beta_2 = \beta_3 = 0 \; . \tag{3.53}$$

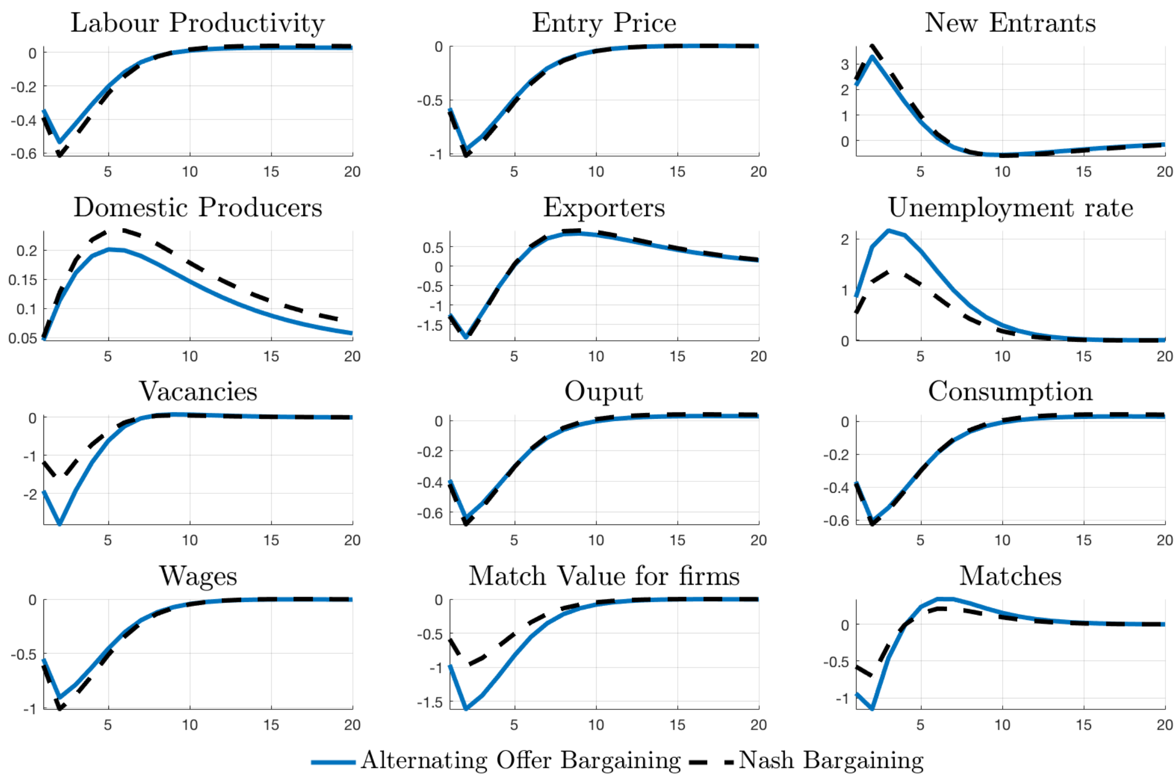

Figure 3.3: Alternating offer vs Nash bargaining

Note: Impulse Response Functions to a four standard deviation uncertainty shock to the technology process. The IRFs are in terms of % deviations from the ergodic mean (stochastic steady state). The horizontal axis depicts periods in quarters.

The two key results from this experiment is that wage inertia is important for the dynamics of labour market variables, but it plays a minor role in terms of the impact of uncertainty on total output and consumption.

In the baseline model, which features endogenous wage stickiness as discussed in Section 3.3.2 [14] the negative response of unemployment is more pronounced, as due to inertial wages the value of match surplus for firms, $\mathcal{J}$, shrinks relatively more and the drop in vacancies is higher. Under NB, unemployment, matches and vacancies move in the same direction as in the model with AOB but their response is slightly muted as the adjustment occurs along the wage margin to a larger degree.

[14]For a more in-depth discussion on the properties of AOB see Christiano et al. (2016)

However, the dynamics of consumption and output are almost indistinguishable between the two settings. The relatively higher drop of wages under NB, feeds into a lower price for intermediate goods and thus lower sunk costs for potential entrants, which drives up the mass of domestic producers, N_d. However, because new entrants are characterized by lower idiosyncratic productivity, and thus contribute relatively less to total output, the response of aggregate output and consumption is very similar to the model with AOB.

Sensitivity Analysis

To ensure that the results are robust to different parameter combinations I perform sensitivity analysis. The results are reported in more detail in Appendix 3.

Firstly, I investigate the role of nominal price rigidities for the transmission of uncertainty shocks. The main finding is that the qualitative response of key variables remains unchanged under flexible prices, but price stickiness delivers significant amplification. As shown in Figure 3.C.3, the contractionary effects of uncertainty are materially dampened under flexible prices as final producers can adjust along the price margin. This mutes the negative impact of uncertainty for the intermediate good sector, where search frictions occur, and thus it mutes the negative impact of uncertainty on employment, breaking the negative feedback loop between precautionary behaviour, aggregate demand and unemployment. I find that when prices can adjust flexibly, the negative impact of uncertainty on aggregate output and consumption drops by a tenfold.[15]

Additionally, I repeat the simulations varying the parameter values that determine the elasticity of substitution across home and foreign goods, η. In the baseline calibration, the intratemporal elasticity of substitution between home and foreign goods, which is also the elasticity of substitution across domestic non-traded goods, η, is set to 3.8 as in Ghironi and Melitz (2005). The implied mark-up over marginal costs is relatively high, at 35%.[16] I test the sensitivity of the responses to

[15] This is consistent with Leduc and Liu (2016) who also report a large amplification role (up to a twenty-fold) for price rigidities in models with frictional labour markets.

[16] As analysed in Ghironi and Melitz (2005), even though mark-ups over marginal costs are relatively high, due to the presence of fixed export cost, the mark-up over average costs is significantly lower.

a range of values for the elasticity of substitution and find that results are in line with the baseline study.

Finally, I look at the sensitivity of results when varying labour market parameters such as κ and ζ, which capture the size of recruiting costs and the relevance of the outside option in the bargaining process. The main message of this chapter remains unchanged from these robustness exercises.

3.7 Conclusion

This paper aims to address the consequences of an uncertainty shock for trade and labour market dynamics. I do so through the lens of an open economy DSGE model with rich micro-foundations for trade and frictional labour markets which is calibrated to the UK. More specifically, this framework allows for endogenous producer entry and self-selection of heterogeneous firms into exporting in order to study how uncertainty shocks affect the extensive margin of trade. I also build endogenous wage rigidities through a search and matching framework in which agents play an alternating offers bargaining game.

Our analysis shows that the precautionary savings motive of households propagates the uncertainty shock through two channels. The first one is standard in the literature; households reduce their aggregate demand and increase savings with contractionary effects for output which are amplified due to search frictions. The second channel arises from the interplay of precautionary behaviour and endogenous producer entry. Firm entry increases in response to an uncertainty shock as entry costs get lower. Due to a higher mass of less productive non-trading firms entering the domestic market, there is a reduction in the mass of exporters, who face higher competition from domestic producers on input goods and there is a drop in average productivity. Uncertainty has inflationary effects in this framework, as it shifts the distribution of firm-level productivity to the left, acting as a negative aggregate supply shock.

We should note that several dimensions of uncertainty in small open economy models are not addressed in this paper. A significant one is the impact of uncertainty for labour supply, from both native and immigrant households. I defer the question of how uncertainty interacts with migration decisions to future research.

Acknowledgements I would like to thank Andrea Ferrero for his advice and feedback. I would also like to thank Francesco Zanetti and Harris Dellas for helpful discussion and comments. This paper has benefited from the warm hospitality, presentations and conversations with economists at the Bank of England. Finally, I would like to thank PhD students and postdocs at the University of Oxford for conversations and suggestions. I am particularly grateful to Alex Haas and Rajssa Mechelli for their support and feedback. The views expressed and any remaining errors are my own.

Appendices of chapter 3

Description of appendix to Chapter 3

Section 3.A derives some additional equilibrium conditions mentioned in Chapter 3, while Section 3.B summarizes the calibration strategy. Section 3.C presents figures discussed in the main text, as well as additional experiments.

3.A Mathematical appendix

Final producers

Sectoral good producers set prices $\rho_{d,t}$ and $\rho^h_{x,t}$ in order to maximise their expected stream of dividends, taking the demand for Y_d and Y_x as given. Producers that contribute to the domestic bundle maximise the expected discount stream of profits from domestic production

$$d_t = \mathbb{E}_t \sum_{s=0}^{\infty} \beta_{t,t+s} \left(\rho_{d,s}(1 - \tfrac{\Xi}{2}(\tfrac{P_{d,s}}{P_{d,s-1}} - 1)^2)Y_{d,s} - \varphi_{d,s} Y_{d,s} \right) \tag{3.54}$$

taking the following demand schedule as given

$$Y_{d,s} = (\rho_{d,s})^{-\xi} Y_s \ . \tag{3.55}$$

After substituting the constraint (3.55) rewriting $\varphi_{d,t}$ as $N_{d,t}^{1\eta-1} \varphi \tilde{z}_d$ from equation (3.33), and deriving the first order condition with respect to $P_{d,t}$ we get the following expression

$$\rho_{d,t} = \frac{\eta(P^c_{d,t}/P_t)}{(\eta-1)(1-\frac{\Xi}{2}(\Pi_{d,t}-1)^2) + \Xi(\Pi_{d,t}-1)\Pi_{d,t} - \Xi\mathbb{E}_t\beta_{t,t+1}(\Pi_{d,t+1}-1)\frac{\Pi^2_{d,t+1}}{\Pi_{c,t+1}}\frac{Y_{d,t+1}}{Y_{d,t}}} \tag{3.56}$$

The analogous optimality condition with respect to $P^h_{x,t}$ yields

$$\rho^h_{x,t} = \frac{\tau\eta(P^c_{x,t}/P_t)}{(\eta-1)(1-\frac{\Xi}{2}(\Pi^h_{x,t}-1)^2) + \Xi(\Pi^h_{x,t}-1)\Pi^h_{x,t} - \Xi\mathbb{E}_t\beta_{t,t+1}(\Pi^h_{x,t+1}-1)\frac{{\Pi^h_{x,t+1}}^2}{\Pi_{c,t+1}}\frac{Y_{x,t+1}}{Y_{x,t}}} \ , \tag{3.57}$$

where the PPI inflation rates are defined as $\Pi_{d,t} = \frac{P_{d,t}}{P_{d,t-1}}$ and $\Pi^h_{x,t} = \frac{P^h_{x,t}}{P^h_{x,t-1}}$.

More compactly, the above can be written as in equations (3.40) and (3.41), where $\mu_{d,t}$ and $\mu_{x,t}$ are the time-varying markups defined as

$$\mu_{d,t} = \frac{\eta}{(\eta-1)(1-\frac{\Xi}{2}(\Pi_{d,t}-1)^2) + \Xi(\Pi_{d,t}-1)\Pi_{d,t} - \Xi\mathbb{E}_t\beta_{t,t+1}(\Pi_{d,t+1}-1)\frac{\Pi^2_{d,t+1}}{\Pi_{c,t+1}}\frac{Y_{d,t+1}}{Y_{d,t}}} \tag{3.58}$$

$$\mu_{x,t} = \frac{\eta}{(\eta-1)(1-\frac{\Xi}{2}(\Pi_{d,t}-1)^2)+\Xi(\Pi_{d,t}-1)\Pi_{d,t}-\Xi\mathbb{E}_t\beta_{t,t+1}(\Pi_{d,t+1}-1)\frac{\Pi^2_{d,t+1}}{\Pi_{c,t+1}}\frac{Y_{d,t+1}}{Y_{d,t}}} \tag{3.59}$$

Note that under price flexibility, markups are constant and the relative prices collapse to

$$\frac{P_{d,t}}{P_t} = \frac{\eta}{\eta-1}\frac{P^c_{d,t}}{P_t}, \qquad \frac{P_{x,t}}{P^*_t} = \frac{\eta}{\eta-1}\frac{\tau}{Q}\frac{P^c_{x,t}}{P_t}\ , \tag{3.60}$$

Alternating offer bargaining

The AOB wage is derived as the solution of a finite horizon Rubinstein bargaining game via backward induction. Following Christiano et al. (2016), I assume that in the terminal subperiod M, the worker makes a take-it-or-leave-it offer to the firm such that $\mathcal{J}_{M,t} = 0$. It is useful to rewrite the game in terms of the present value of the real wage, $w^p_{j,t}$, for each subperiod defined as

$$w^p_{j,t} = w_{j,t} + \rho\mathbb{E}_t\beta_{t,t+1}w^p_{t+1} \tag{3.61}$$

with w^p_{t+1} denoting the present value of the real wage over the next M subperiods. We can do a similar decomposition over the firm's expected present value of the match, which can be re-written as

$$\mathcal{J}_t = \varphi_t + \mathbb{E}_t\beta_{t,t+1}\varphi^p_{t+1} - \left(w_t + \mathbb{E}_t\beta_{t,t+1}w^p_{t+1}\right) \tag{3.62}$$

Then expressing the Bellman Equations for workers and firms in terms of w^p and φ^p variables yields

$$\mathcal{V}_t = w^p_t + \mathcal{C}_t \tag{3.63}$$

where C_t is the continuation value of the job-match

$$\mathcal{C}_t = \rho\mathbb{E}_t\beta_{t,t+1}\mathcal{C}_{t+1} + (1-\rho)\left(\mathbb{E}_t\beta_{t,t+1}(q^u_{t+1}\mathcal{V}_{t+1} + (1-q^u_{t+1})\mathcal{U}_{t+1}\right) \tag{3.64}$$

with $\mathcal{U}_t$ defined as in equation (3.17) The value of the unemployment state for workers is

$$\mathcal{U}_t = \phi + \mathbb{E}_t\beta_{t,t+1}\left\{(q^u_{t+1}\mathcal{V}_{t+1} + (1-q^u_{t+1})\,\mathcal{U}_{t+1})\right\}\ . \tag{3.65}$$

The above specification allows us to conveniently recast the AOB game in terms of the current real wage, the intermediate good price and their discounted present values. Specifically, the worker's indifference condition in all odd subperiods is given by

$$\begin{aligned} w_{j,t} + w_t^p + \mathcal{C}_t = \zeta \left(\tfrac{M-j+1}{M}\phi + \mathbb{E}_t \beta_{t,t+1} \left\{ \left(q_{t+1}^u \mathcal{V}_{t+1} + \left(1 - q_{t+1}^u\right) \mathcal{U}_{t+1} \right) \right\} \right) \\ +(1-\zeta) \left(\tfrac{\phi}{M} + w_{j+1,t} + w_t^p + \mathcal{C}_t \right) \ , \end{aligned} \tag{3.66}$$

while, the intermediate good firm's indifference condition in all even subperiods is given by

$$\frac{M-j+1}{M}\varphi_t + \varphi_t^p - (w_{j,t} + w_t^p) = (1-\zeta)\left(-\tilde{\gamma} + \frac{M-j}{M}\varphi_t + \varphi_t^p - (w_{j+1,t} + w_t^p) \right) + \zeta \times 0 \ . \tag{3.67}$$

In the final subperiod M, the RHS is zero, which yields

$$w_{M,t} + w_t^p = \frac{1-M}{M}\varphi_t + \varphi_t^p; . \tag{3.68}$$

By sequentially substituting the terms $w_{j,t}$ and $\varphi_{j,t}$ into $w_{j+1,t}$ and $\varphi_{j+1,t} \forall j \in [1, M]$ we can re-write the terminal indifference condition as[17]

$$w_t^p = \alpha_1 \varphi_t^p + \alpha_2(\mathcal{U}_t - \mathcal{C}_t) + \alpha_3 \tilde{\gamma} + \alpha_4(\varphi_t - \phi) \ , \tag{3.69}$$

where $\alpha_1 = \frac{1-\zeta+(1-\zeta)^M}{2-\zeta}$, $\alpha_2 = \frac{1-(1-\zeta)^M}{2-\zeta}$, $\alpha_3 = -\frac{\alpha_2(1-\zeta)(2-\zeta)}{\zeta} + \alpha_1(2-\zeta)$ and $\alpha_4 = \frac{(1-\zeta)\alpha_2}{M} + 1 - \alpha_2(2-\zeta)$.

Finally, using the definitions over the firm's and worker's expected present value of the match and the worker's value of unemployment, (3.62), (3.63) and (3.65) respectively, we can re-write the wage expression as the surplus sharing expression (3.21) in Chapter 3.

$$\mathcal{J}_t = \beta_1(\mathcal{V}_t - \mathcal{U}_t) - \beta_2\tilde{\gamma} + \beta_3(\varphi_t - \phi) \ . \tag{3.70}$$

[17]For the proof please see Christiano et al. (2016).

3.B Calibration

TABLE 3.B.1. **PARAMETER CALIBRATION**

Parameters	description	Value	References/Targets
β	subjective discount factor	0.995	2% annual real interest rate
γ	relative risk aversion	2	Ghironi and Melitz (2005)
η, ξ	elasticity of substitution between differentiated goods	3.8	Ghironi and Melitz (2005)
δ	firm exit probability	0.026	10.5% UK business death rate
ψ	portfolio adjustment costs	0.0025	Schmitt-Grohe and Uribe (2003)
z_{min}	lower bound in Pareto distribution	1	Normalization
k	Pareto shape parameter	3.4	Ghironi and Melitz (2005)
f_e	entry costs	1	Normalization
f_x	fixed export costs	0.0072	15% of UK firms exporting
ϵ	elasticity of matches to workers	0.5	Literature
ρ	exogenous job survival rate	0.95	UK job separation rate
ϕ	unemployment benefit	1.23	Replacement ratio of 0.4
κ	vacancy posting costs	0.68	Target $\kappa V^{ss} = 1\% Y^{ss}$
$\tilde{\gamma}$	bargaining delay costs	0.02	$U^{ss} = 5\%$, $q = 0.7$
ζ	probability of negotiation breakdown	0.2%	Christiano et al. (2016)
M	quarterly bargaining rounds	60	Christiano et al. (2016)
μ	matching efficiency	0.58	$U^{ss} = 5\%$, $q = 0.7$
Ξ	price adjustment cost	80	Cacciatore and Ghironi (2020)
ϕ_i	Taylor-rule smoothing coefficient	0	Literature
ϕ_π	Taylor-rule coefficient on inflation gap	1.5	Literature
ϕ_y	Taylor-rule coefficient on output gap	0.2	Literature
	Parameters for the shock process		
ρ_z	first moment TFP shock persistence	0.9	Literature
ρ_σ	second moment TFP shock persistence	0.76	Leduc and Liu (2016)
σ	steady-state volatility of TFP shock	0.01	Literature
η_σ	volatility of second moment TFP shock	0.3	Leduc and Liu (2016)
ρ_λ	first moment preference shock persistence	0.9	Basu and Bundick (2017)
ρ_{σ_λ}	second moment preference shock persistence	0.7	Basu and Bundick (2017)
σ^λ	steady-state volatility of preference shock	0.03	Basu and Bundick (2017)
η_{σ_λ}	volatility of second moment preference shock	0.005	Basu and Bundick (2017)

3.C Additional IRFs

Figures 3.C.1 and 3.C.2 display the responses of the model economy to a four-standard-deviation uncertainty shock to the volatility of the discount factor. Specifically, I consider an extension of the model in which preferences are specified as following

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \lambda_{t+s} \left(\frac{C_{t+s}^{1-\gamma}}{1-\gamma} \right) , \tag{3.71}$$

where λ_t follows an AR(1) process

$$\ln \lambda_t = (1-\rho_\lambda) \ln \lambda + \rho_\lambda \ln \lambda_{t-1} + \sigma_t^\lambda \epsilon_t^\lambda , \tag{3.72}$$

where $\rho_\lambda \in (0,1)$ captures the persistence of the preference shock and ϵ_t^λ is a random variable following an i.i.d. standard normal distribution. The term σ_t^λ is the volatility of the preference shock, following an AR(1) as well

$$\ln \sigma_t^\lambda = (1-\rho_{\sigma_\lambda}) \ln \sigma^\lambda + \rho_{\sigma_\lambda} \ln(\sigma_{t-1}^\lambda) + \eta_{\sigma_\lambda} \epsilon_t^{\sigma_\lambda} , \tag{3.73}$$

where the parameter $\rho_{\sigma_\lambda} \in (0,1)$ captures the persistence of the uncertainty shock and the term $\epsilon_t^{\sigma_\lambda}$, is the second-moment, mean preserving shock.

It is worth noting that qualitatively, the model economy responds in the same way as in the baseline model where uncertainty is introduced in aggregate productivity.

Figure 3.C.3 displays the responses of the baseline model economy under flexible prices, confirming the importance of price stickiness for the amplification of uncertainty shocks.

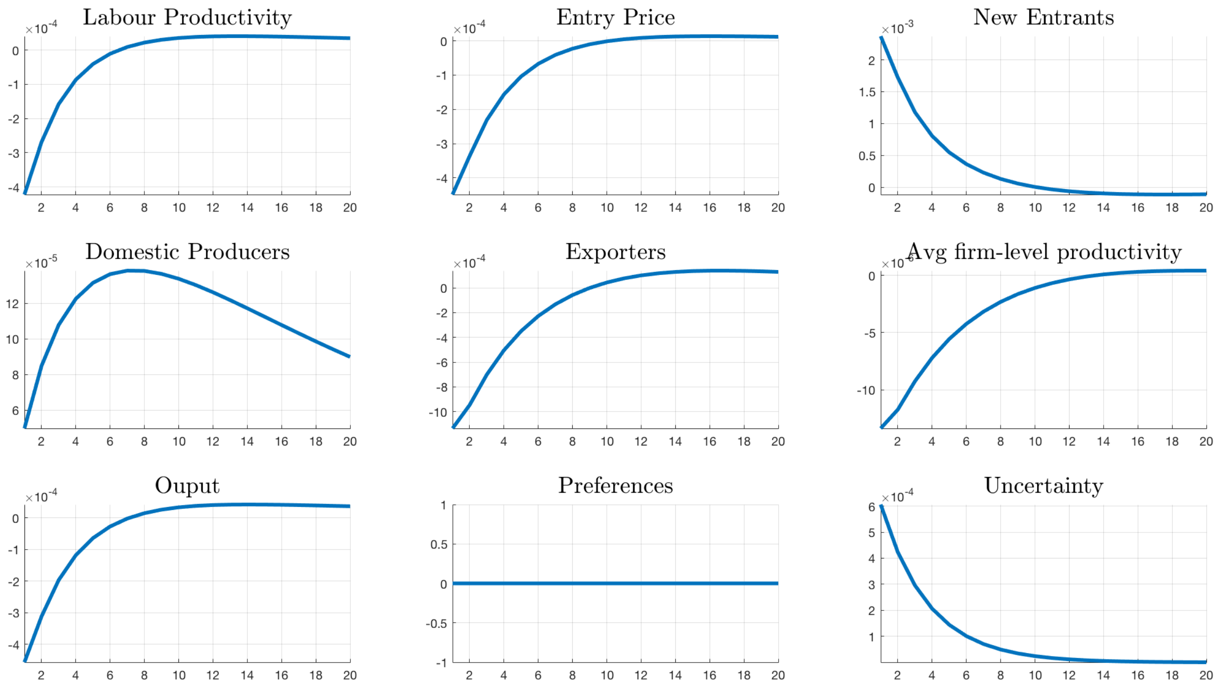

Figure 3.C.1: Impact of a preference uncertainty shock (a)

Note: The IRFs are in terms of % deviations from the Impulse Response Functions to a four standard deviation uncertainty shock to the discount factor shock's ergodic mean (stochastic steady state) apart from the responses of the uncertainty shock which are in absolute deviations from steady state. The horizontal axis depicts periods in quarters.

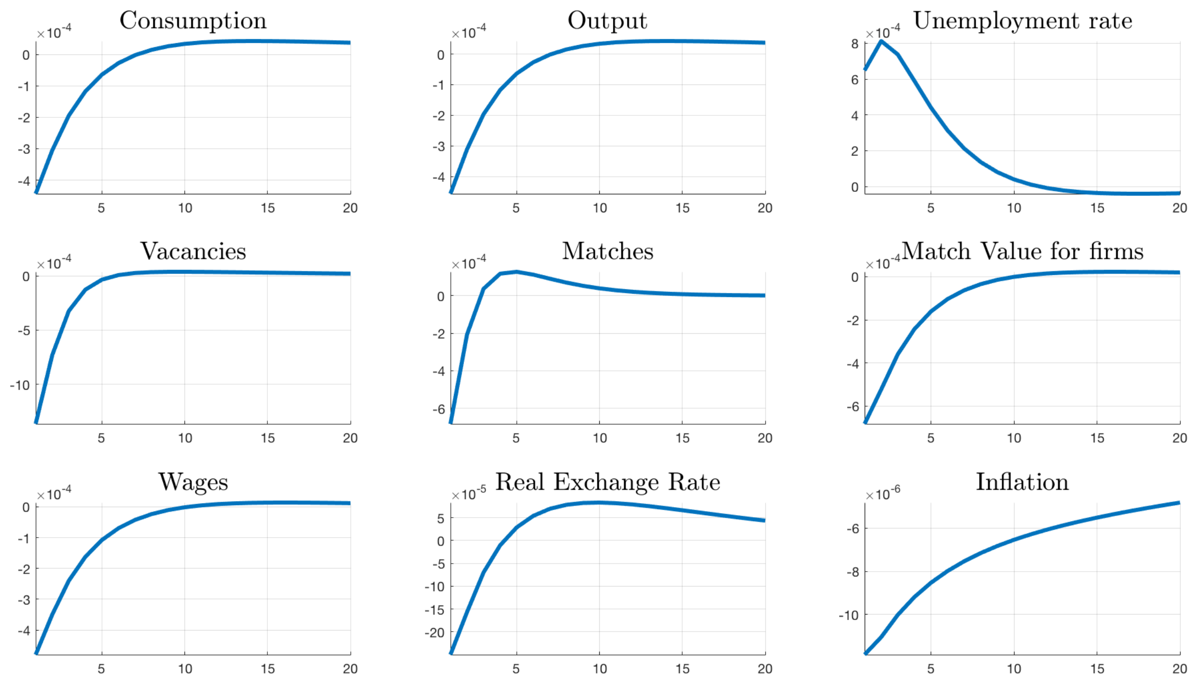

Figure 3.C.2: Impact of a preference uncertainty shock (b)

Note: The IRFs are in terms of % deviations from the Impulse Response Functions to a four standard deviation uncertainty shock to the discount factor shock's ergodic mean (stochastic steady state). The horizontal axis depicts periods in quarters.

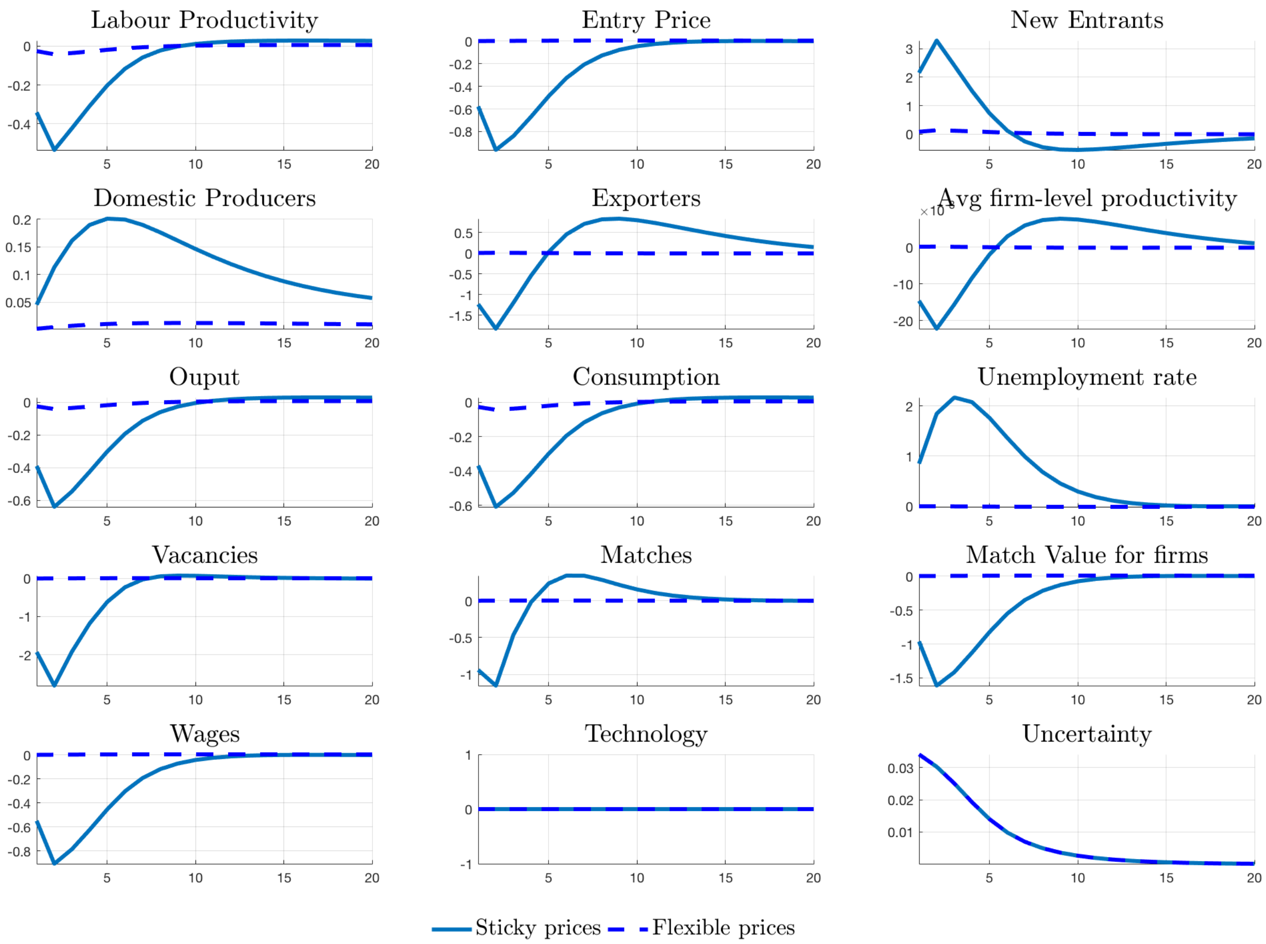

Figure 3.C.3: Sensitivity analysis (a)

Note: The IRFs are in terms of % deviations from the Impulse Response Functions to a four standard deviation uncertainty shock to the technology shock's ergodic mean (stochastic steady state). The horizontal axis depicts periods in quarters.

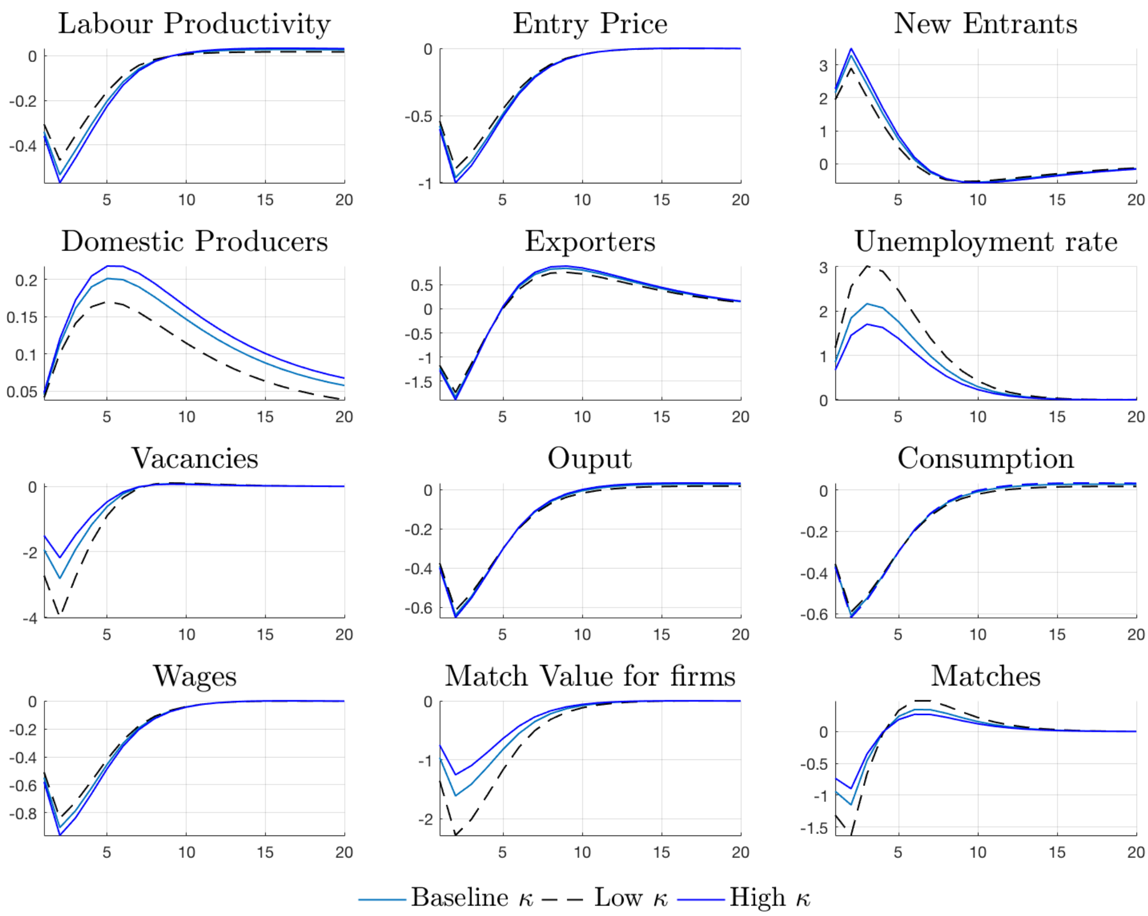

Figure 3.C.4: Sensitivity analysis (b)

Note: The IRFs are in terms of % deviations from the Impulse Response Functions to a four standard deviation uncertainty shock to the technology shock's ergodic mean (stochastic steady state). The horizontal axis depicts periods in quarters. The baseline, low and high κ scenarios refer to total vacancy posting costs equal to 1%, 1.5% and 0.5% of steady state output respectively.

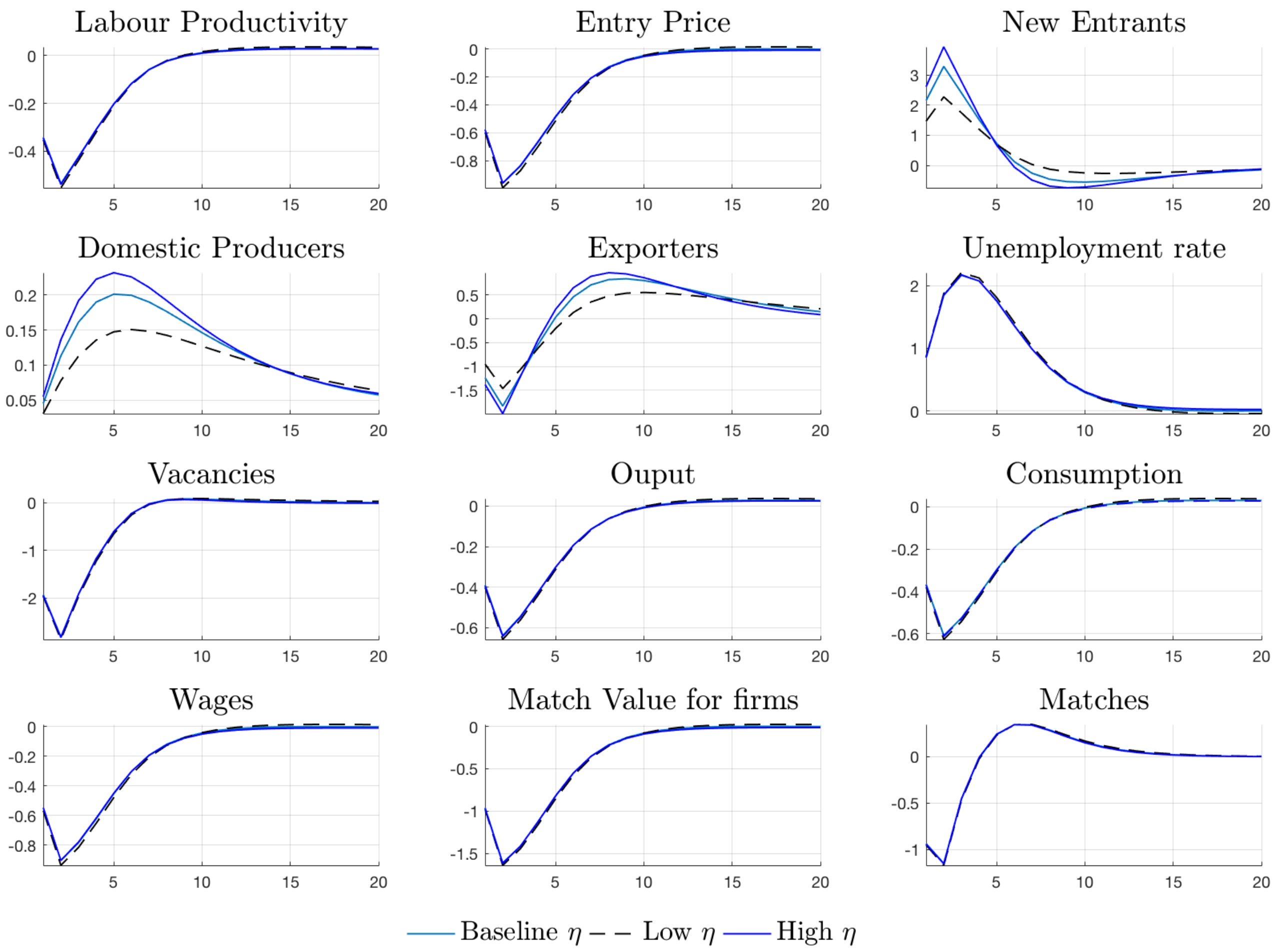

Figure 3.C.5: Sensitivity analysis (c)

Note: The IRFs are in terms of % deviations from the Impulse Response Functions to a four standard deviation uncertainty shock to the technology shock's ergodic mean (stochastic steady state). The horizontal axis depicts periods in quarters. The baseline, low and high η scenarios refer different values for the elasticity of substitution parameter which is set at 3.8, 3 and 4.3 respectively.

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