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JEL Classification: O31, O41, O38, F12, F42, F43

Keywords: Innovation policy, Endogenous growth theory, International policy coordination, Eu integration, Fdi spillovers

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Innovation Union: Costs and Benefits of Innovation Policy Coordination*

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Keywords: Optimal innovation policy, growth theory, international policy coordination, EU integration, FDI spillovers.
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1 Introduction

The recent financial crisis has increased the demand for stronger international economic policy coordination on the one hand, while also triggering movements toward more policy independence on the other. While some European countries are promoting an 'ever closer union' agenda of further policy coordination, in a historical referendum the UK voted to terminate its EU membership. While there is sufficient consensus that trade integration should not be reversed, less agreement can be found on the virtues of unified, or coordinated, policy in other areas such as banking, fiscal and innovation policies. In the aftermath of the 2008 financial crisis, the debate on the completion of Europe's Economic and Monetary Union intensified around the needs and the breadth of a future fiscal and banking union (Berger et al. (2018)).

In 2010, the EU launched the Innovation Union, a flagship initiative of the Europe 2020 strategy. This was an ambitious and wide plan; one aspect was the creation of a single market for innovation via the introduction of the Unitary Patent — a procedure aimed at radically cutting the bureaucratic cost of patenting in the EU. Another was strong financial support of innovative firms, grant/subsidies for innovative small-medium enterprises (SME instruments) and a specific innovation procurement budget (European Commission (2015)). Moreover, the Commission's recent proposal of a plan for a Common, Consolidated, Corporate Tax Base, which includes an R&D incentive, can be seen as a first step toward a unified tax treatment of R&D (d'Andria et al. (2017)). These and other initiatives from the Commission can be interpreted as an initial step toward some degree of unification of innovation policy.

Motivated by these political and institutional developments, this paper provides a macroeconomic framework to evaluate the effects of innovation policy and assess the costs and benefits of policy coordination in an economic union. One fundamental task in exploring these issues is to identify the key structural differences between countries and understand their role in shaping the aggregate effects of policy coordination and their distribution across regions. Another important task for the analysis of optimal policies is to identify the key market distortions that policy must correct.

We document large differences between EU members in innovation performance and in innovation policy. These differences are especially pronounced when comparing the new member states (NMS), the eastern European countries that entered with the enlargement starting in 2004, and the Old member states (OMS), all western European countries. Both innovation inputs (R&D-GDP ratio, scientists and engineers share of workforce) and innovation output (patents) are substantially larger in the old EU members. Some non-negligible innovation dynamism, though, can be observed in NMS, showing early signs of catching up. Along with a surge in innovation in the NMS, we observe similarly strong dynamics of inward FDI. Using firm-level data from the Business Environment and Enterprise Performance Survey (BEEPS), we provide new evidence of FDI spillovers, linking the innovation performance in NMS, and in other central and eastern European countries, with the surge in FDI and foreign firms' presence. Finally, we document a wide heterogeneity in both government funding of business R&D and indirect support via tax incentives, both between old and new members and within each group.

Guided by these facts, we construct a Schumpeterian growth model with two large regions, the 'West' and the 'East'. In both regions, firms compete in quality for market leadership; investment in innovation allows firms to improve the quality of their products. The key asymmetry between the two regions is that firms in the West are better at innovating: they have a more efficient R&D technology. The regions are connected via trade and flows of ideas. The latter travel across the border via knowledge spillovers: each firm's innovation produces knowledge spillovers which improve innovation of the other firms. Although firms can learn from knowledge produced worldwide, these spillovers are locally biased, so firms learn more from other national firms than from abroad. This further intensifies the *innovation gap* between the two regions. The innovation technology also features a 'congestion externality' at the region level: the productivity of the marginal innovation worker declines with the amount of workers employed in innovation in the region. As a consequence, the optimal global allocation of innovation incentives does not necessarily imply concentrating innovation in the region where R&D is more efficient. Our main policy instrument is a generic R&D subsidy incorporating both direct support and tax incentives.

There are two key reasons for international policy cooperation. Regions want to subsidise innovation for strategic reasons: when a firm from one region innovates and takes the leadership, profits shift across borders, leading to higher income and welfare in the innovating region. Policy cooperation aims at reining-in the subsidy competition due to this *strategic motive*. Second, as typical of endogenous growth models, innovation is the engine of growth and *intertemporal knowledge spillovers* is the transmission channel. When a firm innovates, it produces knowledge on which future innovation builds. Firms do not take this into account and underinvest in innovation from a social point of view, giving scope for policy intervention. Since knowledge spillovers in our framework are in part global and growth benefits both regions via trade, policy cooperation has incentive to subsidise innovation to correct this distortion. The global policy maker wants to subsidise R&D less, or tax it more than in the non-cooperative scenario if the distortions due to the strategic motive are stronger than those due to knowledge spillovers. If instead, knowledge spillovers prevail, cooperation tends to provide stronger innovation incentives.

The gains from policy cooperation then crucially depend on the relative strength of the strategic motive, which derives from firm profitability, and on knowledge spillovers. In our framework, markups are constant but we explore different structures and intensity of spillovers. The baseline model is a 'no-scale' Schumpeterian framework with semi-endogenous growth (e.g. Jones, 1995; Kortum, 1997; Segerstrom, 1998). In this class of models, knowledge spillovers weaken as the economy grows so that long-run growth does not depend on the size of the market and policy has only temporary effects on growth.[1] This is the *weak spillovers* case, which is our baseline model. We then introduce FDI into this

[1]The first generation endogenous growth models have the counterfactual prediction that larger countries have faster long-run growth. Weak knowledge spillover solves this 'scale effect' problem but without preserving the endogeneity of

baseline setup, in the form of an adaptive R&D investment that firms must do to transfer technology and produce abroad. FDI is a vehicle of cross-border knowledge spillovers, where ideas flow across regions via multinational activity. FDI essentially endogenises international knowledge spillovers which became more global as FDI intensifies. This is the *weak spillovers with FDI* case. Finally, we analyse a version of the model without FDI but where *strong spillovers* lead to fully-endogenous growth. Here, policy impacts long-run growth, as in the first generation Schumpeterian models (Grossman and Helpman, 1991b; Aghion and Howitt, 1992), but without scale effects (e.g. Dinopoulos and Thompson, 1998; Howitt, 1999; Peretto, 1998).

We calibrate the baseline model and its variants to aggregate and sectoral data and reproduce key facts of the EU economy, which we divide in two regions: the old member states, the West in the model, and the new member states, the East in the model. We compute the Nash equilibrium R&D subsidies, obtained assuming that the two regions set them non-cooperatively, and the cooperative policy, *harmonised* subsidies, obtained when a global policy maker chooses two potentially different subsidies for the two regions to maximise global welfare.[2] We compute the welfare gains or losses of these cooperative scenarios with respect to the Nash and the observed subsidies scenarios. In doing so, we take into account the full transitional dynamics and explore the impact of different policy horizons. A welfare decomposition allows us to quantify the contribution of the key motives for cooperation and, in particular, to analyse the role of the structure and the intensity of knowledge spillovers in shaping the gains from cooperation.

In the baseline model, subsidy harmonisation requires a tax on Western firms' innovation and a subsidy to Eastern firms' innovation. Harmonised subsidies produce large welfare gains, a 17% consumption increase with respect to Nash and 16% compared to the status quo. The driver of these gains is the internalisation of the strategic motive. Purging innovation by the most efficient region and encouraging it in the less efficient one reduces global innovation and growth temporarily slows down. The non-cooperative policy scenario therefore exhibits too much growth from a global perspective, due to the strategic motive that cooperative policy corrects. The welfare gains from cooperation are concentrated in the East while the West experiences losses, which poses a potential problem for the implementation of the policy. We also explore a range of policy horizons and find that internalising knowledge spillovers is beneficial only for short horizons. Moreover, with short policy horizons no region loses from cooperation.

Introducing FDI endogenises the extent to which spillovers are global. Labor costs are lower in the lagging region, the East, so Western firms have incentive to offshore production. Technology transfer via multinational activity increases the stock of knowledge capital in the East, thereby increasing the knowledge spillovers enjoyed by Eastern firms and their innovation efficiency. FDI substantially changes our results. Cooperation leads to large subsidies for the West and taxes in the East. The gains

the long-run growth. See Jones (forthcoming) for a recent review of this literature.

[2] For completeness, we also explore another cooperation scenarios whereby the policy maker maximises global welfare by choosing a *unified* subsidy for both regions.

from cooperation are driven by knowledge spillovers and are decreasing in the cost of FDI. All regions gain from cooperation. We also consider a specific FDI subsidy and find that setting it cooperatively leads to similar gains as those obtained with R&D subsidies, with a substantial share of the gains accounted for by the knowledge spillover channel.[3]

All these results are driven by the impact of FDI on global spillovers. FDI makes knowledge spillovers more powerful as it facilitates knowledge flows between regions. Since western firms do not take this into account when innovating, they underinvest from a global perspective. Hence, although we keep the same 'weak spillover' assumption of the baseline model, integration via FDI leads to stronger global spillovers which, in turn, play a bigger role, as does growth, in shaping the gains from cooperation. In our semi-endogenous economy with FDI, there is too little innovation from a global perspective and there are gains from cooperation via promoting innovation and temporarily increasing growth.

Finally, we analyse a fully endogenous version of the model. With strong knowledge spillovers and permanent effects of policy on growth, there is a larger underinvestment in innovation in each region and globally. Thus, the gains form cooperation are driven by the internalisation of this externality. As in the weak spillover version with FDI, cooperation is driven by the knowledge spillovers and both regions benefit equally from growth, thus there are no obstacles to implementation.

Literature review. The main related literature is the recent body of work in 'quantitative growth theory' analysing the effects of R&D subsidies both in closed economy (e.g Acemoglu and Akcigit, 2012; Acemoglu et al., 2018; Akcigit et al., 2016) and in open economy (e.g Impullitti, 2010; Akcigit et al., 2018b). Surprisingly, there is very little macroeconomic work on international cooperation in innovation policy. Grossman and Lai (2004) and Kondo (2013) propose theoretical analyses of the gain from intellectual property rights policy cooperation in endogenous growth models. To the best of our knowledge, ours is the first and only paper studying R&D subsidies competition and the gains from global policy cooperation in an endogenous growth model. We also contribute by exploring the role of knowledge spillovers in shaping the gains from policy cooperation, and showing that the two standard specifications of this class of models, the semi and the fully-endogenous, yield substantially different results. Finally, we show that endogenising international knowledge spillovers via FDI reconciles the results of the two standard models. Specifically, that knowledge spillovers and the underinvestment in innovation associated with them are the key sources of the gains from global policy cooperation. Thus we provide two contributions to this literature: first, a quantitative analysis of the gains from global cooperation in R&D subsidies, and second, an exploration of the role of FDI in shaping these gains.

Several papers have introduced FDI in endogenous growth models (e.g. Branstetter and Saggi, 2011; He and Maskus, 2012; Acemoglu et al., 2015; Segerstrom and Jakobsson, 2017). Dinopoulos and Segerstrom (2010) introduce FDI in a North-South Schumpeterian growth model to study the

[3] We limit the analysis to the comparison between cooperation and observed subsidies, as computing the Nash equilibrium along the transition for this more complex model is harder and the solution is less stable.

effects of an increase in the protection of international property rights on innovation and the wage gap between countries. In their model, the lagging country's firms, the southern firms, do not innovate and can obtain global leadership only via imitation. FDI to the South exposes northern firms to imitation. In our FDI extension, we take a similar approach but we generalise the model allowing firms in the lagging region to innovate and model FDI as a vehicle of knowledge spillovers and not as a channel for imitation.

The second-generation endogenous growth theory that has emerged from the solution of the 'scale effect' problem has produced two classes of models which have different predictions regarding the impact of policy on growth. In semi-endogenous models, policy has only transitional effects on growth whereas in fully-endogenous models it impacts the steady state growth rate. There is empirical evidence in favour of both types of models. Macroeconometric analysis using a cross-country time series approach, such as (e.g. Ha and Howitt, 2007; Madsen, 2009, 2011), provide strong support for fully endogenous models and little or no support for semi-endogenous models. Strong support for the latter class of models instead, emerge in recent sector, firm and product level analysis (e.g. Bloom et al., 2020), providing evidence of substantial decreasing returns in the production function of ideas. As this is still an open empirical question, we consider both classes of models and contribute to the literature showing that knowledge spillovers via FDI can reconcile their predictions regarding the welfare benefits from innovation policy cooperation.

The strategic motive for subsidies has been widely studied in the strategic industrial policy literature. Contributions focusing on R&D subsidies are the pioneering Spencer and Brander (1983), and the following work by Leahy and Neary (1997), Leahy and Neary (2009) and Haaland and Kind (2008) among others. Papers analysing the strategic role of trade policy include Eaton and Grossman (1986), Maggi (1996), and more recent contributions by Felbermayr et al. (2013) and Campolmi et al. (2018). In a sequence of recent papers Ossa (2011), (2011), (2014), (2015) revisits the key questions in the literature with a modern quantitative approach. Our contribution to this line of work is to cast the analysis in a dynamic framework and show that internalising intertemporal knowledge spillovers, that is — internalising the growth effect of policies, is crucial and quantitively relevant for the gains from cooperation.[4] We also contribute analysing the role of international knowledge spillovers endogenised via FDI.

The rest of the paper is organised as follows: section 2 presents some stylised facts on R&D policy and innovation in EU states and provides empirical evidence on the link between FDI and innovation. Section 3 presents the baseline model, while the quantitative analysis and the key results are shown in Section 4. Section 5 explores the FDI extension. In section 6, we present the fully-endogenous version of our model. Section 7 concludes.

[4]This results echoes the recent finding in the trade and growth literature showing that the *dynamic gains* from trade magnify the gains obtainable in static models with firm heterogeneity (e.g. Sampson, 2016; Impullitti and Licandro, 2018), Perla et al. (2015).

2 Motivating Facts

We present a set of descriptive statistics providing motivation for our modelling strategy and empirical support for the quantitative analysis. We document a large heterogeneity in innovation activities and innovation policy across European countries. Moreover, we identify a strong relationship between the presence of western multinationals and the innovation activity performed by local firms in eastern European countries.

2.1 Innovation performance and policy support

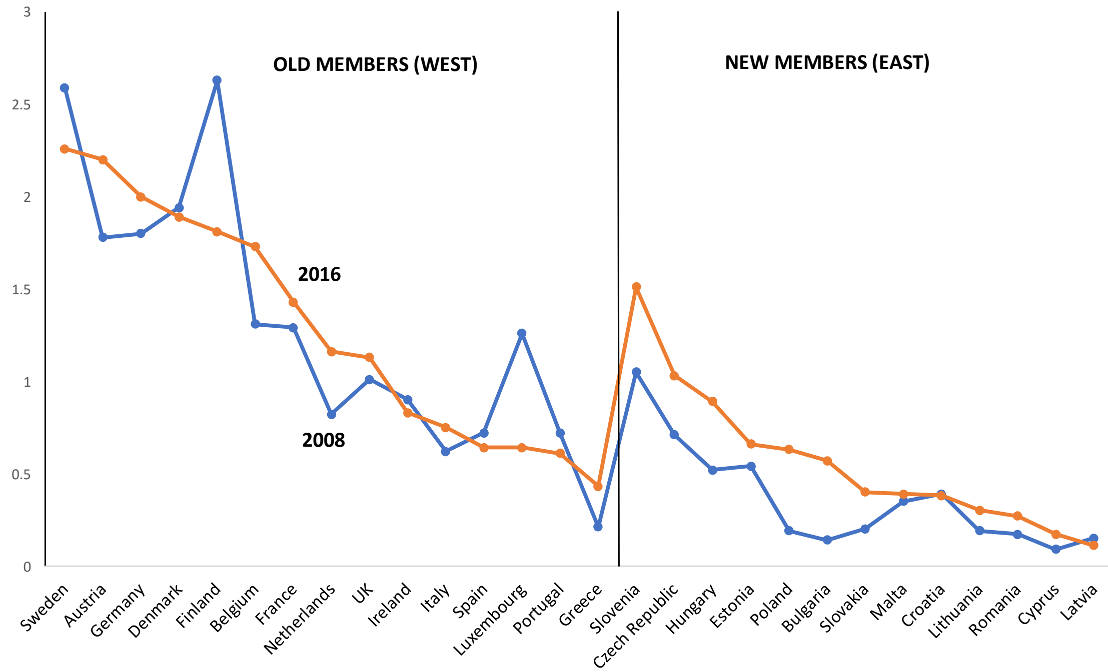
While innovation in Europe is still concentrated in the West, a growing and non-negligible share is performed in the new member states (NMS). Figures 1 and 2 illustrate the differences in innovation efforts for the year 2008 and 2016 between the old (West) and the new (East) members that have joined the European-Union in May 2004 onwards.[5] Business R&D as a share of GDP is substantially higher in western compared to eastern EU countries, with an average of 1.31% for the former and 0.5% for the latter in the period 2008-16.[6] However, several East EU countries, such as Slovenia, the Czech Republic, Hungary, Estonia and Poland show non-negligible and increasing R&D intensity outperforming quite a few old EU members. A similar picture can be obtained looking at the employment share of scientists and engineers in manufacturing. In the period 2008-16, 7.2% of employment in the West was accounted for by scientists and engineers (S&E), while in the East the share is 4.2%. Moreover, the S&E employment share increases in this period in several eastern countries.

Governments can choose among various instruments to promote business R&D, either by providing direct support, such as grants, contracts, loans and subsidies, or through indirect support, such as tax allowances, credits, and accelerated depreciation of R&D capital expenditures. The absence of a common EU innovation policy translates into strong heterogeneity in the public support for innovation. As an illustration, Figure 3 provides the direct and indirect (tax credit) government R&D support in 2012 as a percentage of the countries' GDP by the new and old member states' governments. France and Slovenia provide the most combined R&D funding for business as a percentage of GDP, with more than 0.35 percent of their GDP spent on R&D support. There are striking disparities in both direct and indirect (tax credit) support both for the old and the new member states. Of our sample of 22 countries, all the 16 western EU countries and the 6 new EU members received "direct" government support. In addition, 11 of the 16 old EU members and 3 of the 6 new EU members give "indirect" R&D support, such as tax credit. On average, West EU governments provide direct support to R&D corresponding to about 0.08% of GDP and indirect support through the tax system of a similar amount. In the East, the

[5] The old members are Germany, France, Italy, the Netherlands, Belgium, Luxembourg, Denmark, Ireland, United Kingdom, Greece, Spain, Portugal, Austria, Finland and Sweden. The new members are Czech Republic, Cyprus, Estonia, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia and Slovakia that joined in 2004, Romania and Bulgaria, joined in 2007 and Croatia in 2013.

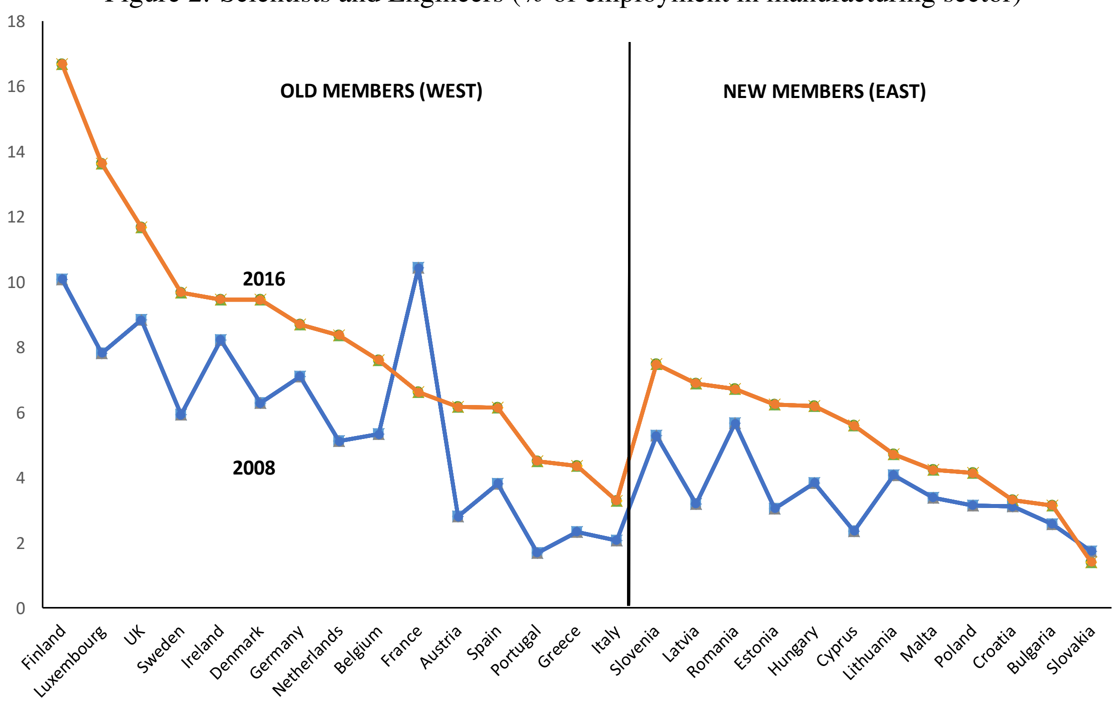
[6] The average difference between East and West is smaller if we consider total R&D, which includes public investment. The West records an average of 2% while the East attains a 0.9%.

Figure 1: Business Enterprise R&D Expenditure (% of GDP)



Source: Eurostat.

Figure 2: Scientists and Engineers (% of employment in manufacturing sector)

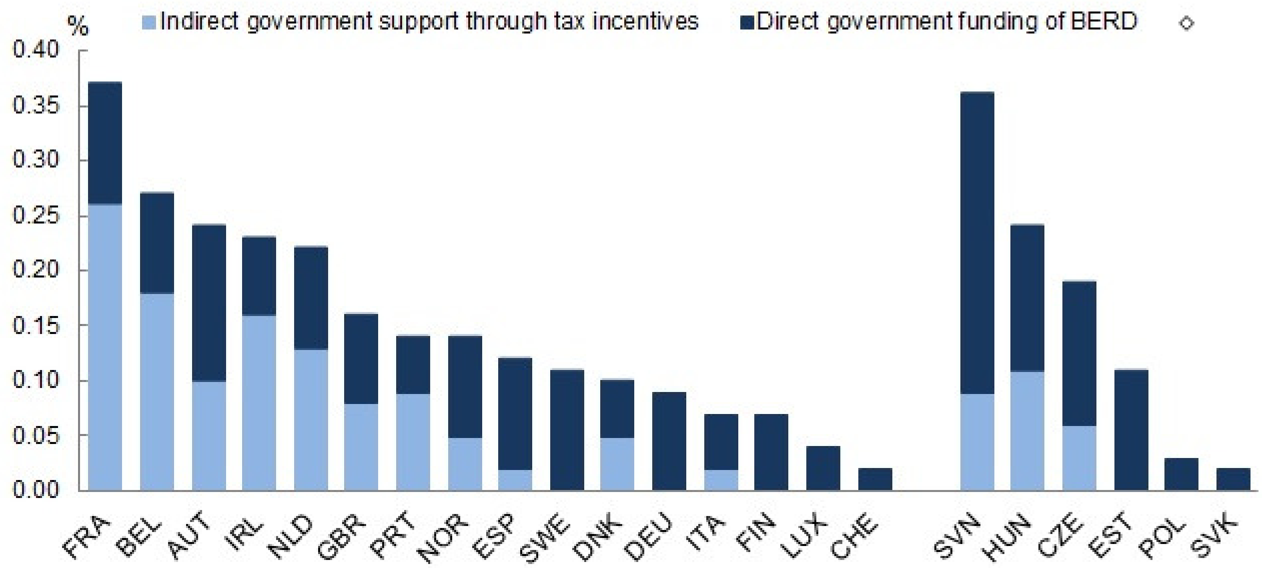


Source: Eurostat.

direct support is larger (about 0.12% of GDP on average) and the indirect incentives amount to 0.03% of GDP.

This set of descriptive statistics deliver two clear messages. First, there is a large heterogeneity in

Figure 3: Direct government funding and Indirect government support through tax incentives, 2012



BERD: business enterprise expenditure on R&D. Source: OECD R&D Tax Incentives Indicators.

innovation performances across EU countries with most of the activity concentrated in the Northern and old member countries. The amount of innovation performed in the new member countries is, though, substantial and growing. Second, the absence of a common EU innovation policy likely produces a strong heterogeneity in the public support for innovation.

2.2 Western multinationals and innovation in the East

Along with the increase in innovation, we observe a marked increase in inward FDI in the new member states. FDI stock as a share of total GDP of NMS doubles between 2001 and 2012. Over this period, the share of FDI stock in the NMS accounted for by the old members remains large and stable around 80% (Eurostat). We dig deeper into the potential relationship between FDI and innovation analysing the empirical link between the presence of multinational affiliates and the local innovation activity of domestic firms. To this end, we rely on the Business Environment and Enterprise Performance Survey (BEEPS) which provides self-reported information from top managers on various types of innovation activity. This firm-level survey based on face-to-face interviews with managers realised during the years 2011-2014, includes 15,694 firms located in Eastern and Central European countries, as well as Russia and Turkey. For those years, the data provide information on the 2-digit sector classification, the exact regional location as well as the ownership of each firm.

An additional key feature of the BEEPS survey is that it includes several questions on product and process innovation. Firms report the introduction of the following innovation in the last 3 years: i) New products or services ii) New production or supply methods iii) New organisational, management practices or structures iv) New marketing methods. Based on this information, we identify domestic firms which report at least one of these new product or process innovations in a given year.[7] This direct firm-level measure of innovation has previously been used by Gorodnichenko et al. (2010) and Gorodnichenko et al. (2015).[8]

Aggregate results. We make use of this information to aggregate the data at the region-sector level and calculate both the share of domestic firms conducting innovation as well as the fraction of firms with foreign capital.[9] We furthermore exclude all region-sector pair with fewer than 10 active firms.[10] Using two-way clustering, we report robust standard errors clustered both at the regional and at the sector level. We regress the share of domestically-owned firms reporting innovations on the share of firms with foreign capital in Table 1. We do this without any additional control in column 1. We then introduce region fixed-effects in column 2 and sector fixed-effects in column 3. In all regressions, we find a positive and significant relationship at the 1% level between the share of domestically-owned firms reporting innovations and the share of foreign affiliates. The positive relationship is also robust to the inclusion of both sets of fixed-effects simultaneously, as in column 4. While the size of the coefficient largely decreases, it remains significant at the 1% level. Raising the share of foreign affiliates from the 25th to the 75th percentile (that is from 0 to 0.083) is associated with a predicted change in the share of domestic firms reporting innovation by 3.3 percentage points.

Table 1: Aggregate results: Share of Domestic firms reporting innovation and share of foreign firms at the region-sector level

Dependent variable: Share of domestic firms reporting innovation at the region-sector level				
	(1)	(2)	(3)	(4)
Share of foreign affiliates	0.701***	0.422***	0.660***	0.401***
	(0.133)	(0.124)	(0.127)	(0.120)
Region fixed-effects	No	Yes	No	Yes
Sector fixed-effects	No	No	Yes	Yes
Observations	346	346	346	346
R-squared	0.140	0.817	0.169	0.835

Robust standard error clustered both at the region and at the sector level into brackets. *, **, *** significantly different from 0 at 10%, 5% and 1% level, respectively.

[7] As the BEEPS survey only reports the number of firms reporting at least one new product or innovation over a 3 year period, we use the binomial distribution formula to recover the probability for a firm to report one additional product in a given year.

[8] While most studies on innovation use patent data or R&D expenditures, these authors argue that these measures are potentially problematic. Patents are likely to capture inventions rather than innovations, while R&D does not necessarily lead to innovation.

[9] We consider as a foreign affiliate a firm with at least 50 percent of the capital owned by a foreign entrepreneur/company.

[10] Increasing the threshold to 20 or 30 active firms would decrease the number of observations but leads to qualitatively similar results.

Firm-level results. We then turn to a firm-level linear-probability model. Focusing on domestic firms, we construct our dependent variable as a dummy variable taking a value one if the firm reports product or process innovations, and zero otherwise. We then construct our main explanatory variable in two different ways: as a dummy variable indicating the presence or absence of a foreign firm within the same region and within the same 2-digit sector than the firm, or as the *count* of foreign firms within the same sector-location. Table 2 reports our main results where all estimations include region, sector and year fixed effects. Regressions (2) and (4) also include additional firm-level controls: firms' log of sales and a set of dummy variables for state-owned enterprises, exporting and importing status. The coefficient associated with 'foreign presence' is significant at least at the 5% level in all the estimations. Considering Column (2), a foreign presence in a region-sector is associated with an increase by 3.5 percentage points of the predicted probability for a domestic firm to report innovation.[11] In the appendix, we also split the sample in many different ways and, as reported in Table A.1, we find more pronounced effects in manufacturing sectors than in services, and for private firms compared to state-owned enterprises. Effects also appear independent of the export and import status of the firm and persistent both for small and large firms (below or above the median size).

Table 2: Firm-level evidence: Domestic firms reporting innovation and foreign presence

Dependent variable:				
Firm-level dummy variable for domestic firms reporting innovation				
Explanatory variable:	dummy	dummy	count	count
	(1)	(2)	(3)	(4)
Foreign presence	0.034**	0.035***	0.014***	0.012***
	(0.014)	(0.013)	(0.003)	(0.003)
Control variables	No	Yes	No	Yes
Observations	14,877	11,466	14,877	11,466
R-squared	0.167	0.209	0.168	0.209

All regressions include region, sector and year fixed effects. Regressions (2) and (4) include the following firm-level control variables: firms' log of sales, and a set of dummy variables for state-owned enterprises, exporting firms, importing firms. Robust standard error clustered both at the region and at the sector level into brackets. *, **, *** significantly different from 0 at 10%, 5% and 1% level, respectively.

While the literature on technology transfer recognises that FDI may act as a vehicle of technological transfer and may facilitate innovation in receiving countries, our suggestive evidence do not imply causation. Nevertheless, our results highlight the geographic clustering of domestic innovative firms in sectors with active foreign affiliates. Our findings complement those obtained by Gorodnichenko et al. (2010) and Gorodnichenko et al. (2015) using similar data for the same set of countries, but for a

[11] Furthermore excluding all region-sector pair with fewer than 10 or 20 active firms as in the aggregate estimations would generate qualitatively similar results with similar sizable effects.

different period of time.[12] While they use firm-level sales to multinational affiliates to identify vertical linkages between domestic firms and foreign affiliates, we use a more general definition capturing the presence of foreign affiliates within the same region-sector.

3 The Model

We consider an economy consisting of two regions: the West, which in our quantitative analysis represent the old EU members, and the East, which represent the new EU members. Labor in each region is employed in two types of activities: manufacturing of goods and innovative R&D which results in a quality upgrade of the goods. Firms in both regions compete in quality for market leadership, and product quality is advanced by investing resources in innovation. The two regions are separated by an *innovation gap*, as Western firms are more productive in innovation than Eastern firms.[13] Once a successful quality innovation has occurred, the innovator earns the global leadership in the sector, which is protected by a patent and lasts until replaced by a national or a foreign innovator. Trade between the two regions is costly and the product cycle within a sector occurs through leapfrogging across the regions, i.e. through an upgrade of the product quality to win over the sectoral leadership previously held by the other region.

3.1 Households

A two-region economy, East and West, is populated by households which have the same intertemporal additively separable preferences over an infinite set of sectors indexed by $\omega \in [0,1]$. Each household is endowed with a unit of labor time whose supply generates no disutility. Households choose their optimal consumption bundle for each date by solving the following optimization problem:

$$\max U^K = \int_0^\infty L_0 e^{-(\rho-n)t} \log u^K(t) dt \tag{1}$$

subject to

$$u^K(t) \equiv \left(\int_0^1 \left[\sum_{j=0}^{j^{\max}(\omega,t)} l^{j(\omega,t)} d^K(j,\omega,t) \right]^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}}$$

$$c^K(t) \equiv \int_0^1 \left[\sum_{j=0}^{j^{\max}(\omega,t)} p^K(j,\omega,t) d^K(j,\omega,t) \right] d\omega$$

[12]The information on the exact region of location of firms is only available for the years 2011-2014. Unfortunately, the information on the firm-level sales to multinational firms used by Gorodnichenko et al. (2010) and Gorodnichenko et al. (2015) is not available for those years.

[13]Nelson (1993) documents how appropriately designed institutions and infrastructure can generate a systemic efficiency in innovation which benefits all innovating firms in a country.

$$W^K(0) - \int_0^{\infty} L_0^K e^{-\int_0^t \left(r^K(s)-n\right)ds} T^K(t)dt = \int_0^{\infty} L_0^K e^{-\int_0^t \left(r^K(s)-n\right)ds} c^K(t)dt,$$

where $K = W,E$ indicates the region, L_0^K is the initial population and n is its constant growth rate, ρ is the common rate of time preference — with $\rho > n$ —- and $r^K(t)$ is the market interest rate on a risk-free bond in region K. $d^K(j,\omega,t)$ is the per-member flow of goods in sector ω, each good of quality level $j \in \{0,1,2,...\}$, purchased by a household at time $t \geq 0$. $p^K(j,\omega,t)$ is the price of a good of quality level j in sector ω at time t, $c^K(t)$ is per-capita nominal expenditure, and $W^K(0)$ is the initial period wealth level. A new vintage of a good ω yields a quality equal to λ times the quality of the previous vintage, with $\lambda > 1$. $j^{\max}(\omega,t)$ denotes the maximum quality in which the good in sector ω is available at time t. As is common in quality ladder models we will assume price competition at all dates, which implies that in equilibrium only the top quality product is produced and consumed in positive amounts in each sector ω. Finally, $T^K(t)$ is the per-capita lump-sum tax used to finance government subsidies to the R&D activities in the economy. We assume governments run balanced budgets every period.

The instantaneous utility function is a quality-augmented CES consumption index, with $\sigma > 1$. Households maximise static utility by spreading their expenditures $c(t)$ across the product lines and purchasing in each line only the product with the lowest price per unit of quality, that is the product of quality level $j = j^{\max}(\omega,t)$. Hence, the household's demand of each product is:

$$d^K(\omega,t) = q(\omega,t)p^K(\omega,t)^{-\sigma}\frac{c^K(t)}{P^K(t)^{1-\sigma}}, \tag{2}$$

where $q(\omega,t) = \lambda^{j(\omega,t)(\sigma-1)}$ is a measure of the good's quality and $P^K(t) = \left[\int_0^1 q(\omega,t)p^K(\omega,t)^{1-\sigma}d\omega\right]^{\frac{1}{1-\sigma}}$ is the quality-price index. As we will show next, goods prices are different in the two regions due to the presence of trade costs. The intertemporal consumption choice leads to,

$$\frac{\dot{c}^K(t)}{c^K(t)} = r^K(t) - \rho, \tag{3}$$

the standard Euler equation.

3.2 Product market

In each region, firms can hire workers to produce any consumption good $\omega \in [0,1]$ using a linear technology with unit labor requirement a^K, where $K = W,E$ is the producer indicator for the Western (W) and the Eastern (E) innovators. The wage rate in $K = W,E$ is denoted by w^K. Patent rights are protected globally by a perfectly enforceable EU-wide patent law. As is usual in Schumpeterian models with vertical innovation (e.g. Grossman and Helpman (1991b) and Aghion and Howitt (1992)), firms conduct R&D activity to improve their good's quality and obtain market leadership. The innovation size is fixed at $\lambda > 1$, so that when an innovation arrives, λ measures the quality gap between the leader and the follower. The patent system grants the quality leader a temporary monopoly which is destroyed when the firm is leapfrogged by the next innovator.[14]

We assume that there is an iceberg trade cost $\tau^K > 1$, such that for one unit of any good to arrive from producer in location K to the export market, τ^K units of good need to be shipped. We restrict our attention to equilibria where $w^E > a^W w^W \tau^W/(a^E\lambda)$, and $w^W > a^E w^E \tau^E/(a^W\lambda)$. These conditions guarantee the existence of a complete product cycle. The first condition states that the innovation quality improvement is large enough for a western quality leader to have a lower quality-adjusted production cost than an eastern firm one step below on the quality ladder. If wages are lower in the East this condition suggests the western quality leader can drive the lower cost competitor out of the market. Similarly, the second condition states that the quality jump is large enough to allow the eastern innovator to leapfrog the western innovator and become the global leader.

We follow the common practice and assume that to participate in pricing competition, in each product line, firms must pay a small fee (e.g. Howitt, 1999; Dinopoulos and Segerstrom, 2010; Akcigit et al., 2018b). Under this assumption, the profit maximising choice of the quality leader is always to charge the domestic monopoly price for domestic sales:[15]

$$p^K(\omega,t) = \frac{\sigma}{\sigma-1} a^K w^K(t), \tag{4}$$

and the export monopoly price, denoted by $*$, for sales in the other region:

$$p^{*K}(\omega,t) = \frac{\sigma}{\sigma-1} a^K w^K(t)\tau^K, \tag{5}$$

Substituting (4) and (5) for the price in the static consumer demand (2), and using it to express the total (domestic and export) monopoly profits accruing to global quality leaders we obtain

$$\pi^K(\omega,t) = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} (a^K w^K(t))^{1-\sigma} q(\omega,t)\left(\frac{c^K(t)L^K(t)}{P^K(t)^{1-\sigma}} + \frac{c^J(t)L^J(t)}{P^J(t)^{1-\sigma}}(\tau^K)^{1-\sigma}\right), \tag{6}$$

where $c^K(t)$ and $c^J(t)$ are per capita expenditures in $K,J = W,E$, with $K \neq J$, and $L^K(t)$ and $L^J(t)$ are the labor sizes of the two regions, respectively. We choose the western wage to be the numeraire of our economy, $w^W = 1$.

[14]For simplicity, we assume that the patent length is infinite. Generalising the model to patents of finite length is straightforward but complicates the analysis without yielding any relevant new insight.

[15]Typically in these models the quality leader charges the monopoly price when the innovation is 'drastic', which implies a large λ, and the limit price with non 'non-drastic' innovation, low λ. Under our assumption of costly participation, with non-drastic innovation, if the followers enter the game the leader will first charge limit price, then, after the follower has left, will revert to monopoly price. The follower has no incentives to play this game and, as a consequence, the leader can always charge the monopoly price.

3.3 Global R&D races

In each sector, incumbent leaders are challenged by entering firms that employ workers in research to discover the next best-quality version of their products. The arrival rate of innovation in sector ω at time t is $I(\omega,t)$, which is the aggregate summation of the Poisson arrival rates of innovation produced by all firms targeting the new product in sector ω. Each firm i can obtain an arrival rate of innovation according to the following technology:

$$I_i^K(\omega,t) = A^K(\omega,t)^{1-\alpha} l_{Ri}^K(\omega,t) L_R^K(\omega,t)^{-\alpha}, \tag{7}$$

for $K = W, E$, where $A^K(\omega,t)$ measures the productivity of R&D in sector ω, region K, $l_i^K(\omega,t)$ is the R&D labor employed in firm i in the same sector and region, and $L_R^K(\omega,t) = \sum_i l_{Ri}^K(\omega,t)$ is the total labor used for R&D in sector ω, region K. This technology implies that each firm's instantaneous probability of success is a decreasing function of the total national R&D investment in the sector, $0 < \alpha < 1$. The region-specific nature of decreasing returns in R&D can be motivated by the presence of fixed costs, such as lab equipment, by institutional and/or cultural differences, and finally by a given supply of workers with heterogeneous research abilities[16].

The productivity term $A^K(\omega,t)$ is region and sector-specific and determines the structure of knowledge spillovers:

$$\begin{aligned} A^W(\omega,t) &= \gamma^W \left(\frac{q(\omega,t)}{\hat{Q}^W(t)^\phi} \right)^{-1} \text{ for } \omega \in \omega^W, \\ A^E(\omega,t) &= \gamma^E \left(\frac{q(\omega,t)}{\hat{Q}^E(t)^\phi} \right)^{-1} \text{ for } \omega \in \omega^E, \end{aligned} \tag{8}$$

where ω^W and ω^E are the set of sectors with western and eastern leaders respectively, and $\hat{Q}^W(t) = Q^W(t)^\beta Q(t)^{(1-\beta)}$, $\hat{Q}^E(t) = Q^E(t)^\beta Q(t)^{(1-\beta)}$, $1/2 < \beta < 1$, $0 < \phi < 1$ and $\gamma^W > \gamma^E$. Following Li (2003) and Minniti et al. (2013), R&D efficiency in our model is lower for sectors with higher quality, which implies that innovating becomes more difficult over time as $q(\omega,t)$ increases and the target of innovation becomes more complex. Moreover, the presence of knowledge spillovers implies that R&D efficiency increases with the aggregate quality. In our open economy, these spillovers have a rich structure which combines local and global sources. The local spillovers derive from the aggregate quality of the goods produced by local firms $Q^K(t) = \int_{\omega^K} q(\omega,t) d\omega$, while the global spillovers come from the aggregate global quality $Q(t) = \int_0^1 q(\omega,t) d\omega$. Assuming $\beta > 1/2$ introduces a local bias to spillovers.[17], which along with the assumption that the productivity parameter γ^W is higher than γ^E,

[16] See Eaton and Kortum (1999) and Impullitti (2010) for further insight.

[17] This is consistent with the empirical evidence on the local nature of technological spillovers (Audretsch and Feldman, 2003; Gorodnichenko et al., 2015).

gives the West a comparative advantage in R&D.[18]

In order to address the 'scale effect' problem affecting the first generation endogenous growth models, we impose decreasing returns to the knowledge spillovers (Jones, 1995).[19] Spillovers become less powerful as the aggregate quality grows, which allows us to obtain a stationary growth rate that is independent of population size. As we will see later, this solution to the scale effect problem implies that policies have only a temporary effect on growth, as the long-run growth rate is exogenous and proportional to population growth. For this reason this version of the Schumpeterian model is known as the 'semi-endogenous' growth model.[20]

In our model, as in the standard Schumpeterian model, the 'Arrow effect' (Aghion and Howitt, 1992; Grossman and Helpman, 1991b) operates and innovation is only done by entrants whereas incumbents have no incentives to innovate. Hence the free entry condition fully characterises the equilibrium innovation effort in the economy. Governments subsidise R&D expenditures at the rate s^K, which is region-specific. Each entrant firm chooses the amount of labor devoted to R&D equating the expected returns, $v^K(\omega,t)I_i^K(\omega,t)dt$, where $v^K(\omega,t)$ denotes the value of a patent as discounted stream of profits while $I_i^K(\omega,t)dt$ denotes the instantaneous probability of a successful innovation, with the entry cost incurred. The cost of entry is $(1-s^K)w^K(t)l_{Ri}^K(t)dt = (1-s^K)w^K(t)I_i^K(\omega,t)A^K(\omega,t)^{\alpha-1}L_R^K(\omega,t)^{\alpha}dt$, where we have used (7) to substitute for the entrant's R&D labor l_{Ri}^K. Free entry into R&D races equates the above benefits and costs of innovation, $v^K(\omega,t)A^K(\omega,t)^{1-\alpha}L_R^K(\omega,t)^{-\alpha} = (1-s^K)w^K(t)$, generating the following equilibrium condition:

$$v^K(\omega,t)A^K(\omega,t)I^K(\omega,t)^{\frac{\alpha}{\alpha-1}} = (1-s^K)w^K(t), \tag{9}$$

where we have substituted for the total R&D labor in sector ω region K by the total innovation arrival rate in the same sector/region, $I^K(\omega,t) = \sum_i I_i^K(\omega,t)$, obtained from (7) aggregated to the sectoral level.

To derive the value of a firm, or a patent $v(\omega,t)$, note that a shareholder of the quality leader in sector ω receives a dividend $\pi^K(\omega,t)dt$ over the time interval dt. At the same time, the value of the patent changes by $\dot{v}(\omega,t)dt$, while the shareholder suffers a loss of $v(\omega,t)$ if a subsequent innovation occurs, an event happening with probability $I^K(\omega,t)$. This is Schumpeterian *creative destruction*: successful innovation of some firms comes at the expense of other firms. The presence of efficient financial markets implies that the expected rate of return from holding a stock of a quality leader is equal to the riskless rate of return $r^K(t)$ that can be obtained through complete diversification. Taking limits as dt approaches zero, one arrives to the following no-arbitrage condition for the stock

[18] The higher γ allows western firms to win more innovation races and therefore lead in a larger share of sectors, $\omega^W > \omega^E$. This extensive margin implies that the aggregate quality of goods produced by western firms is higher, $Q^W > Q^E$, and therefore they enjoy stronger spillovers than eastern firms, due to the local bias. This, in turn, reinforces the advantage in R&D efficiency produced by the higher γ.

[19] First generation Schumpeterian models have the counterfactual implications that the long run growth rate is proportional to population size.

[20] See Jones (1995), Kortum (1997), Segerstrom (1998) for different versions of this class of models.

market: $\frac{\pi^K(\omega,t)}{v^K(\omega,t)} + \frac{\dot{v}^K(\omega,t)}{v^K(\omega,t)} = r^K(t) + I^K(\omega,t)$. In equilibrium, the dividend rate plus the rate of capital gains/losses equals the riskless interest rate plus a premium for the risk of being driven out of business by further innovation. It follows that the expected value of a firm (patent) is:

$$v^K(\omega,t) = \frac{\pi^K(\omega,t)}{r^K(t) + I^K(\omega,t) - \frac{\dot{v}^K(\omega,t)}{v^K(\omega,t)}}. \tag{10}$$

Substituting for this into the free entry condition (9) we obtain:

$$\frac{\pi^K(\omega,t)}{r^K(t) + I^W(\omega,t) + I^E(\omega,t) - \frac{\dot{v}^K(\omega,t)}{v^K(\omega,t)}} A^K(\omega,t) I^K(\omega,t)^{\frac{\alpha}{\alpha-1}} = (1-s^K) w^K(t) \ \text{ for } K = W, E. \tag{11}$$

This version of the free entry condition summarises the factors shaping the incentives to innovate in our model. The benefit of R&D is pinned down by the value of the firm and the productivity of innovation. The former is positively driven by the profits of becoming a market leader and negatively affected by creative destruction, the global amount of innovation targeting that sector. Innovation productivity is crucially shaped by the term $A^K(\omega)$, which incorporates the exogenous efficiency parameter γ and the knowledge spillovers, and by the curvature of the R&D technology governed by α. We have assumed that the West is more productive, $\gamma^W > \gamma^E$, and since spillovers have a local bias this implies that R&D also has stronger spillovers in the West. On the other hand, decreasing returns α imply that concentrating all research in one region might not be globally efficient, as we will see later. The model is closed with labor market clearing conditions for the two regions, which can be found in the appendix along with the closed-form solution for the balanced growth path.

3.4 Welfare

Next, we derive the expressions for welfare. The intertemporal budget constraint is given by $\dot{\mathscr{A}}^K(t) = w^K(t) + r^K(t)\mathscr{A}^K(t) - c^K(t) - n\mathscr{A}^K(t) - T^K(t)$, where $\mathscr{A}^K(t)$ denotes the total assets per capita, and $T^K(t)$ is the lump-sum tax per capita that is used to finance the subsidised share of the R&D labor cost in region K. We can write the region K per-capita nominal consumer expenditure as

$$c^K(t) = w^K(t) + (r^K(t) - n)\mathscr{A}^K(t) - \dot{\mathscr{A}}^K(t) - T^K(t), \tag{12}$$

where taxes per capita are given by $T^K(t) = s^K \frac{1}{L^K(t)} \int_{\omega^K} L_R^K(\omega,t) d\omega$. The total stock of per capita assets in each region is defined as the per capita value of all businesses whose creation is financed by the consumers in that region,[21]

[21] We assume full 'home bias' in asset ownership, following the empirical evidence surveyed in Coeurdacier and Rey (2013).

$$\mathscr{A}^K(t) = \int_{\omega^K} \frac{v^K(\omega,t)}{L^K(t)} d\omega. \tag{13}$$

Finally, instantaneous utility is given by

$$u^K(t) = \frac{c^K(t)}{P^K(t)}, \tag{14}$$

implying that each period welfare is represented by real consumption. The price index is $P^K(t) = \bar{P}^K(t)Q(t)^{1/(1-\sigma)}$, with $\bar{P}(t)^K$ measuring the contribution of western and eastern quality leaders to the price index, $\bar{P}(t)^W = [q(t)^W p(t)^{W(1-\sigma)} + q(t)^E p(t)^{*E(1-\sigma)}]^{\frac{1}{1-\sigma}}$ and $\bar{P}(t)^E = [q(t)^W p(t)^{*W(1-\sigma)} + q(t)^E p(t)^{E(1-\sigma)}]^{\frac{1}{1-\sigma}}$. The domestic and export prices of the two regions (4) and (5) are weighted by the relative qualities $q^K(t) = Q^K(t)/Q(t)$ which measure the geographical distribution of market leadership.[22]

Aggregate quality at time t is pinned down by the total number of innovations from time zero to t. Its growth rate, $g(t)$, is thus fuelled by innovation performed in the West and the East, and it can be shown to be

$$g(t) = \frac{\dot{Q}(t)}{Q(t)} = (\lambda^{\sigma-1} - 1)[I(t)^W + I(t)^E]. \tag{15}$$

Utility grows due to the impact of innovation-induced quality growth on the price index. The growth rate of utility is then

$$\frac{\dot{u}(t)}{u(t)} = \frac{1}{\sigma - 1}\frac{\dot{Q}(t)}{Q(t)}. \tag{16}$$

In steady state, this growth rate is exogenous and pinned down by population growth, $g = n/(1-\phi)$. Moreover, the steady state has the geographical component of the price index $\bar{P}^K$ and expenditure as constants, so households' lifetime utility given by equation (1) can be written as

$$\begin{aligned} U^K &= \int_0^\infty L_0^K e^{-(\rho-n)t}(\log c^K(t) - \log P^K(t))dt \\ &= \frac{\log c^K}{\rho - n} - \frac{\log \bar{P}^K}{\rho - n} + \frac{n}{(1-\phi)(\sigma-1)(\rho-n)^2}. \end{aligned} \tag{17}$$

In the steady state, innovation subsidies affect welfare via per-capita nominal consumption level c^K and the impact of the geographical leadership distribution on the price index $\bar{P}$. Growth in the long-run is exogenous in this class of models, and innovation has only 'level' effects on real income and consumption. Innovation has 'growth' effects along the transition, so in order to fully capture the dynamic welfare gains from innovation, the welfare measure must take into account the transitional dynamics.

Accounting for the transitional dynamics implies that expenditure and the price index $\bar{P}^K(t)$ become

[22] Recall that the aggregate quality of goods with K leader is a function of the quality and of the share of goods in which K firms are leaders.

time dependent and the growth rate not only varies with time, but away from the steady state the two regions will typically have a different growth rate. Households' lifetime utility given by equation (1) represents the present value of the infinite horizon path of the three components, $c^K(t)$, $\bar{P}^K(t)$ and $Q(t)$ and can be written as

$$\begin{aligned} U^K &= \int_0^\infty L_0^K e^{-(\rho-n)t}(\log c^K(t) - \log P(t))dt \\ &= \int_0^\infty e^{-(\rho-n)t} \log c^K(t)dt + \int_0^\infty e^{-(\rho-n)t} \log \bar{P}^K(t)dt \\ &\quad + \frac{1}{1-\sigma}\int_0^\infty e^{-(\rho-n)t}\left(\int_0^t g(\hat{t})d\hat{t}\right)dt. \end{aligned} \tag{18}$$

In our analysis of the different policy scenarios, we decompose the welfare effects of subsidies separating the channels operating via consumption and the geographical component of the price index, and the more intrinsically dynamic component due to quality growth. We perform the welfare analysis both including the transitional dynamics and focusing on the steady state only, to highlight the importance of fully accounting for the dynamic welfare gains brought about by innovation and policy cooperation.

3.5 Innovation externalities and the motives for R&D subsidies

To understand the effects of R&D subsidies on welfare and the determinants of the optimal level of these subsidies we need to discuss the externalities produced by innovation. Schumpeterian growth models feature several externalities originating from innovation which shape the scope for policy intervention. Understanding these external effects provides theoretical guidance for the quantitative analysis that follows. We first provide an analytical derivation of the key innovation externalities using a simplified version of our framework and then provide a heuristic discussion of the richer features that they acquire in the full model. For clarity of exposition we start with the closed economy and derive the standard externalities (e.g. Grossman and Helpman, 1991a; Segerstrom, 1998). We then move to uncharted territory and show how these externalities acquire new richer features when the economy is open to trade.

A simplified framework. We take a special case of our CES preferences, where the elasticity of substitution across varieties is one. This implies that limit pricing becomes the optimal pricing strategy, that is $p = a\lambda w$, and we assume $a = 1$. Taking the wage as the numeraire, $w = 1$, log utility implies that the quantity consumed of each good is $c/p = c/\lambda$, where c is expenditure per capita. We use a simple linear R&D technology, assuming $\alpha = 0$ and $A(\omega,t) = A$ constant.[23]

We follow Grossman and Helpman (1991a) procedure and suppose that an external agent (a

[23] As typical in this class of models, a linear R&D technology implies that the model jumps directly to the steady state (see e.g Grossman and Helpman, 1991a).

Martian) has achieved a single innovation in some product line j at time t. We perturb the market equilibrium from that period onwards, so that we preserve the original innovation path, and compute the impact on the welfare of all agents other than the one who collects the profits from the innovation (the Martian). We ignore the profits of the external innovator because innovating firms' private costs are exactly balanced by private benefits.

First, we write (1) as

$$U(t) = \int_t^\infty e^{-(\rho-n)(s-t)} \ln\left(\frac{c(s)}{\lambda}\right) ds + \int_t^\infty e^{-(\rho-n)(s-t)} \left[\log(\lambda)\Phi(s)\right] ds, \tag{19}$$

where $\Phi(s)$ is the total number of innovation successes before time t. We perturb the market equilibrium by $d\Phi(t)$ for every moment in time after time t. The effect of a marginal innovation on the welfare of agents is found by differentiating (19) with respect to $\Phi(s)$,

$$\frac{dU(t)}{d\Phi} = \int_t^\infty e^{-(\rho-n)(s-t)} \frac{1}{c(s)} \frac{dc(s)}{d\Phi(s)} ds + \int_t^\infty e^{-(\rho-n)(s-t)} \log(\lambda) ds. \tag{20}$$

The second term on the RHS of (20) is the growth effect, i.e. the marginal benefit at initial prices from consuming a newly invented higher quality product. The discounted value of this term is $\log(\lambda)/(\rho-n)$. When an innovation is first introduced it benefits consumers immediately as they can buy goods of a higher quality at the same price, but it also benefits consumers in the future as all later innovations build upon past innovations. This externality combines what Grossman and Helpman (1991b) call a *consumer surplus effect*, operating during the life cycle of the new product with what Aghion and Howitt (1992) term an *intertemporal knoweldge spillover* effect which affects future consumers via later innovations. Since innovating firms do not take these effects on consumers into account, they tend to underinvest in innovation. These effects constitute motives to subsidise R&D. The consumer surplus effect is not specific to endogenous growth theory, it is also present in any static model where innovation reduces the price of the good it targets with no future effects.[24] The intertemporal spillover effect is the new key feature brought about by endogenous growth theory.

The first term on the right side of (20) captures the loss in aggregate spending as the effect of the marginal innovation. Added innovation reduces the profits of agents (other than the innovator) and their spending falls. This is the *business-stealing* effect produced by the very nature of Schumpeterian competition (Aghion and Howitt, 1992). When a quality laggard firm successfully innovates, it drives the incumbent firm in its product line out of business. The appropriation of the incumbent firm's monopoly profits reduces the income of the households owning those firms, thereby reducing aggregate consumption and lowering the profits of the other leading firms. The innovating firm does not take this into account and is therefore bound to over-invest in R&D. This is a motive for taxing innovation.[25]

[24]This is present in static models of strategic industrial policy (e.g. Spencer and Brander, 1983; Eaton and Grossman, 1986; Haaland and Kind, 2008).

[25]Another motive for taxing R&D comes from the market structure. Markups produce not only a static distortion, as goods are under-provided but also a dynamic one, since too little inputs devoted to production implies that too much of them are allocated to R&D (e.g. Denicolo' and Zanchettin, 2014). To simplify the exposition we do not discuss this in

To derive this effect, first note that the aggregate spending $c(s)$ equals total income (wages plus profits) minus the spending/investment in R&D[26], $c(s) = 1 + \Pi(s) - I(s)/A$. Since we take the rate of innovation to be unaffected by the external innovation, the changes in expenditures triggered by the latter equal the change in profits. Profits are $\Pi(s) = c(s)(\lambda - 1)/\lambda$. If no other innovation takes place before time s, the economy loses the profits $c(s)(\lambda - 1)/\lambda$ at time s. This profit loss in the innovating industry has also a multiplier effect on the profits of other firms in the economy, as it induces a drop in aggregate spending, which reduces sales in all other industries. The aggregate change in profits is then, $d\Pi(s)/d\Phi(s) = -c(s)(\lambda - 1)/\lambda + (dc(s)/d\Phi(s))(\lambda - 1)/\lambda$. Since, $dc(s)/d\Phi(s) = d\Pi(s)/d\Phi(s)$, the expected reduction in spending at any time $s \geq t$ is $dc(s)/d\Phi(s) = -(\lambda - 1)c(s)e^{-I(s-t)}$, which takes into account the probability of no other innovation success occurring between t and s, with I being the equilibrium arrival rate of innovation.[27] Substituting this into (20), we obtain the external effects of the innovation on welfare:

$$\frac{dU(t)}{d\Phi} = \underbrace{\frac{\log(\lambda)}{\rho - n}}_{\substack{CS+IS \\ (+)}} - \underbrace{\frac{\lambda - 1}{I + \rho - n}}_{\substack{BSE \\ (-)}}. \tag{21}$$

The consumer surplus and intertemporal knowledge spillovers are positive externalities and therefore represent a motive for subsidising innovation while the business stealing effect is a negative externality and motivates a welfare maximising planner to tax innovation. Although our scope here is to provide theoretical insights and not necessarily a fully closed form expression for the externalities, the latter is attainable for this simple model. In order to obtain the innovation arrival rate in closed form we need to specify the R&D technology and use the free entry condition along with the expenditure expression specified above. As shown in the appendix, using a simple linear R&D technology we obtain $I = A(\lambda - 1) - (\rho - n)$.

We now turn to the open economy. To gain insight, we analyse a simple version of our open economy which allows an easy comparison with the closed economy. We assume that the two countries differ in their market leadership due to differences in some primitives. The specific nature of the differences in primitive parameters is not relevant for the analysis. To facilitate comparison with the closed economy and focus on the impact of business stealing on profits, we follow Impullitti (2010) and abstract from labor market effects, assuming that once a firm innovates, it can decide to locate production anywhere at no additional cost. Thus the labor market is global and, as for the closed economy, we take the wage as the numeraire.

We can write the expenditures in the two countries as follows: $c^W(s) = (1 + \Pi(s))\hat{\omega} - I^W(s)/A$

detail, we also find it to be second order quantitatively.

[26]This is another way of writing (12), which allows us to simplify the algebra of computing the external effects.

[27]The arrival rate of innovation follows a Poisson process, so the time duration of R&D races is exponentially distributed with parameter I, the equilibrium arrival rate. Therefore, the probability that a further innovation occurs between time t and s is $1 - e^{-I(s-t)}$.

and $c^E(s) = (1+\Pi(s))(1-\hat{\omega}) - I^E(s)/A$, where the first term on the right hand side represents the labor income of production workers, $\hat{\omega}$ is the share of industries with West leadership and profits per sector, $\Pi(s) = (c^W(s)+c^E(s))(\lambda-1)/\lambda$, depend on global demand. We proceed as above to determine the welfare impact of an external innovation. We assume that an external agent successfully innovates on a product line where the incumbent leader is an Eastern firm and focus on the impact of this innovation on Western welfare.[28] This scenario allows us to highlight the key differences between the closed and the open economy.

The consumer surplus and intertemporal spillovers part is identical, except that now in the open economy, consumers from both countries benefit from the higher quality goods introduced by each innovation, no matter where the innovator comes from. The business stealing effect instead, changes substantially. There is no direct loss in profits for the West, as none of its leading firms is replaced by the external innovation. Profits are shifted from the Eastern leader to the external agent and the only profit loss for Western firms operate via the multiplier effect of the reduction in Eastern expenditures. The Eastern country instead experiences both the direct profit shifting effect due to leadership loss and the indirect effect via the expenditure multiplier.[29] To facilitate comparisons with the closed economy we assume that the two countries are symmetric and that the open and closed economies have the same steady state innovation path.[30] Following the same procedure as in closed economy we obtain,

$$BSE^W_{open} = \int_t^\infty e^{-(\rho-n)(s-t)} \frac{1}{c^W(s)} \frac{dc^W(s)}{d\Phi(s)} dt \quad = \quad \left(\frac{\lambda-1}{2I+\rho-n}\right)\frac{\lambda-1}{2\lambda} < BSE^W. \qquad (22)$$

In the open economy then, the business stealing effect of innovation is weaker because the direct impact of innovation on the profits of non-innovating firms can be borne entirely by the foreign country. This provides a key insight on the welfare impact of R&D subsidies, which will be the core of our analysis that follows. If we replace the external innovator with a Western firm, our results suggest that the business stealing effect of innovation is weaker for the West, as part of it, the direct profit-shifting is offloaded to the other country. Thus there is a *strategic motive* which implies that policy makers are less likely to tax innovation in open economy.

The methodology used to derive the innovation externalities based on the experiment of an external innovator does not allow for the profit shifting effect, typical of the strategic trade and industrial policy literature (e.g. Spencer and Brander, 1983; Eaton and Grossman, 1986; Leahy and Neary, 1997). That literature utilises partial equilibrium models with only one firm per country competing oligopolistically. The business stealing effects consists of shifting the additional profits brought about by innovation

[28] The case in which the external agent innovates on a product line with West leadership has an impact on the Western economy similar to that in closed economy.

[29] We are focusing only on how the open economy affects the external impact of innovation on profits, abstracting from the potential effects on the terms of trade, the relative wages. This could produce a further benefit for the West, in our example, although this disappears in the symmetric countries case which we analyse below.

[30] Recall also that the innovation by the external agent does not change the original innovation path of the economy.

from the foreign to the home firm. This profit-shifting increases home welfare, thereby providing a reason for governments to subsidise R&D. Our method based on the external agent shows that this is not an innovation externality that the government should act to correct, but a pure strategic motive to subsidise innovation by national firms. In our quantitative analysis of the welfare impact of subsidies, both types of strategic motives will play a role, the direct profit-shifting and the general equilibrium business stealing derived in (22). They both combine to suggest that national policy markers in the open economy want to tax less or, more likely, subsidise R&D more for strategic reasons.

Although the simple model does a good job capturing most aspects of the innovation externalities embedded in our full model, it misses one key feature, the role of *international knowledge spillovers*. R&D technology (8) implies that, if intertemporal knowledge spillovers are to some degree global, innovation by one country improves the R&D efficiency in the other country. This is not taken into account either by the innovating firm nor by an individual country's policy maker but it matters for policy cooperation, to which we now turn.

International cooperation. The external effects of innovation and the strategic policy distortions discussed above drive the incentives for international policy cooperation. The non-cooperative policy maker seeks to internalise the business stealing effect by taxing innovation and the consumer surplus and growth effect by subsidising innovation. The strategic motive provides further incentives to subsidise innovation. Hence, the Nash equilibrium subsidies will be negative if the business stealing effect prevails and will be positive otherwise.

Policy cooperation corrects the distortions produced by the strategic motive and by the two positive innovation externalities.[31] The global policy maker, whose scope is to maximise global welfare, is more likely to tax R&D than the local (non-cooperative) ones to correct for the distortions produced by the strategic motive. Moreover, since innovation by a firm in one country affects growth and innovation technology in the other country via international spillovers, the global policy maker is more likely to subsidise R&D than the local ones in order to internalise these positive innovation externalities. It follows that cooperative R&D subsidies can be,

i. lower than Nash subsidies, if the strategic motive is dominant;

ii. higher than Nash subsidies, if consumer surplus and knowledge spillovers are dominant.

The external effects discussed above have been derived in framework where countries are symmetric. In our full model economy, countries are structurally different in their R&D efficiency, which produces a crucial difference in the growth externality. Since $\gamma^W > \gamma^E$, innovation is more productive in the West which, as we will see later, implies that western firms will be the quality leaders in a larger set of industries. Hence, knowledge spillovers $\hat{Q}^K$ in (8) will be larger for the West, thereby leading to a larger underinvestment in innovation for firms in this region. Consequently, cooperative policy has the

[31] The domestic business stealing effect does not play a role in cooperative policy.

incentive to subsidise West R&D more. On the other hand, the innovation technology (7) features a local externality, which makes the productivity of a firm's R&D in a region/sector declining in the total amount of R&D labor devoted by firms in the same region/sector. The smaller is α, which regulates the strength of this externality, the more the global planner wants to diversify R&D and subsidise innovation in the East more than in the West. This *diversification* channel implies that the global policy maker might want to subsidise firms in the two regions at different rates and that the subsidy rate in the West might not necessarily be higher than in the East.

In the quantitative analysis we use these theoretical insights to interpret our numerical results. Although all the externalities and distortions discussed above are important for optimal R&D subsidies, the welfare implications of policy cooperation are essentially driven by the *strategic motive* and by *intertemporal spillovers*. We follow the decomposition of welfare suggested in (17) and (18) and separate the impact of different policy scenarios into the component operating via changes in expenditures, which embeds the distortions due to the strategic motive, and the components operating via the effects of innovation on the price level where the growth rate and therefore knowledge spillovers operate.[32] The externalities governing the diversification channel can operate both via expenditure or prices, so they are more difficult to measure but their role can be easily uncovered by the differences in the cooperation subsidies between the two countries.

4 Quantitative analysis

Next, we calibrate the model to EU data and perform a rich set of quantitative exercises. We compute optimal non-cooperative R&D subsidies, where countries set their policy rate to maximise their own welfare. We then explore our cooperation scenario where the planner chooses different subsidies for each country to maximise global welfare. We also briefly look at another cooperation scenario where the global planner chooses a single unified subsidy rate to maximise global welfare.

4.1 Calibration

We calibrate the parameters of the model to match empirical regularities of the EU economy in the 2005-2016 period. We focus on moments generated by the model's steady state. There are 15 parameters. Three of them, ρ, n, ℓ^W, and the two R&D subsidies, s^W and s^E, are assigned their values directly using data from Eurostat and the OECD. We set ρ (equal to the interest rate r in the steady state) to 0.0404 to match the average Maastricht Treaty EMU convergence criterion series related to the interest rates for long-term government bonds in the EU. Next, we select the value for n to match the average population growth rate in the EU of 0.44%. We calculate the West relative labor force size

[32] For completeness we also report the geographical component of the price index, which embeds the consumer surplus effect, as it carries the impact of innovation on prices abstracting from the knowledge spillovers. Its role in shaping the welfare impact of subsidies is similar to that of knowledge spillover and mostly quantitatively small. Hence we do not emphasise it in our discussion.

(ℓ^W) of 0.801 from the population data. Finally, we use the values for the subsidies of the two regions of 12.2% and 9.7% for the West and the East, respectively, which are the average values of the OECD B-index (large firms) measuring the business tax subsidy rates on R&D expenditures in the 2005-2016 period, obtained from the OECD Main Science and Technology Indicators Database. In the benchmark calibration, the iceberg trade costs for both West and East are taken to be unity.[33] We normalise the production efficiency a^W to one.

The remaining parameters are calibrated internally in a way that best matches the model's steady state to empirical facts of the EU economy, i.e. the long-run averages for the old and the new EU member states. The European Union, EU28, consists of the two groups: EU15 (old members, the West) which includes Belgium, France, Germany, Italy, Luxembourg, the Netherlands, Denmark, Ireland, the U.K., Greece, Portugal, Spain, Austria, Finland and Sweden, and the EU13 (new members, the East) which includes Cyprus, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, Bulgaria and Romania. We assume that the extent to which spillovers are local is the same for both regions, that is, $\beta^W = \beta^E = \beta$.

We match the Eastern relative wage (w^E) of 0.61, measured as the relative average net earnings in PPP as reported by Eurostat for the 2005-2016 period. The OECD reports a multi-factor productivity growth of 0.66% on average in the period 2005-2016 period for the set of countries we consider, which we target. We also target the shares of sectors with Western and Eastern leadership as the regions' output shares in the total EU output. The shares are calculated from the OECD Analytical Activity of Multinational Enterprises (AMNE) database, which provides insights on the role of multinational enterprises in the global economy, as that it includes information on output of countries according to ownership of the firms. After excluding the output of third-countries-owned enterprises, as well as the output of eastern-owned enterprises in the West, we calculate the share of sectors with Western leadership (ω^W) as the share of output of western-owned firms in the West in the total EU28 output. Our calculations suggest that Western European firms account for 91% of EU output.

We target the West and East 2005-2016 average business sector R&D investment (expenditure) as a share of GDP of 3.87% and 2.12%, respectively. These values are obtained from Eurostat as the 2005-2016 averages of the GDP shares of expenditures on intellectual property products (part of gross capital formation), including software, R&D, and entertainment, literary, and artistic originals. The average share of scientists and engineers in total employment — the R&D labor share — take values of 3.13% and 2.22% for the old and the new member states, respectively (Eurostat, 2005-2016).

Finally, we use the estimates reported in the empirical literature as our target for the innovation elasticity to subsidies. As discussed by Becker (2015), most literature studies the quantitative effects of tax credits on innovation and not the effect of direct subsidies. Subsidies' effects are mostly investigated in terms of the crowding-out effect of private investment. Akcigit et al. (2018a) investigate the R&D elasticity with respect to personal and corporate income taxes. Both at the micro (firm and individual) and macro (state) levels, taxes affect the amount, quality and the location of investment

[33] We take free trade as the benchmark and explore the role of trade cost later.

Table 3: Calibration summary

External parameters	Value	Source
Interest rate ($r = \rho$)	0.04	Eurostat, 2005-2016
Population growth rate (n)	0.44%	Eurostat, 2005-2016
Relative labor size, West (l^W)	0.80	Eurostat, 2005-2016
R&D subsidy, West (s^W)	12.2%	OECD, 2005-2016
R&D subsidy, East (s^E)	9.7%	OECD, 2005-2016
Calibrated parameters	Value	
Utility f-n parameter (σ)	3.30	
Innovative R&D productivity parameter, West (γ^W)	0.20	
Innovative R&D productivity parameter, East (γ^E)	0.10	
Manufacturing productivity, East (a^E)	1.20	
Spillover parameter (β)	0.60	
Quality jump size (λ)	1.80	
Decreasing returns (α)	0.20	
Spillovers curvature (ϕ)	0.70	
Moments	Data (Model)	Source
East relative wage (w^E)	0.60 (0.61)	Eurostat, 2005-2016
MFP growth rate	0.66% (0.66%)	OECD 2005-2016
Share of sectors, West leadership (ω^W)	91% (91%)	OECD, 2005-2016
West R&D expenditure/GDP	3.87% (3.04%)	Eurostat, 2015
East R&D expenditure/GDP	2.12% (1.85%)	Eurostat, 2015
West share of labour in R&D	3.13% (3.71%)	Eurostat, 2015
East share of labour in R&D	2.22% (4.33%)	Eurostat, 2015
West innovation elasticity to subsidy	[0.7, 3.5] (1.23)	Akcigit et al. (2018)
East innovation elasticity to subsidy	[0.7, 3.5] (1.60)	Akcigit et al. (2018)

activity. Focusing on the response in the number of patents to the change in corporate and personal taxes, micro and macro estimates range from -0.7 to -3.5. We take this range (in absolute value terms) as our target range for the innovation elasticity to subsidies. Table 3 summarises our calibrated values and model's fit. Although the model is quite stylised, it matches several of the key innovation and growth moments well.

4.2 Optimal policy scenarios.

We analyse three optimal policy options. A first one in which the two regions set their subsidies non-cooperatively in order to maximise their own welfare — this is the *Nash scenario*. Then we analyse two cooperation options. In the *Harmonised subsidies* scenario, a global policy maker chooses separate rates for the West and the East in order to maximise the joint welfare of the two regions. Then in the *Unified subsidies* scenario, one subsidy common to both regions is chosen to maximise global welfare. In our analysis of policy cooperation we rule out ex-post side payments and compare welfare outcomes with those under non-cooperative policy and observed subsidies from the data. For all experiments, the welfare analysis is conducted taking into account the whole transitional path produced by the changes in subsidies across scenarios. We also report welfare numbers pertaining to considering a comparison only across steady states, to highlight the limits of such an approach.

Solution method. The solution for the transition subsequent to a policy change utilises a shooting-type algorithm in a similar spirit to Spencer (2022). We solve for the pre- and post-reform steady states, which provide start and end points for the simulation respectively. The transition is then mapped using finite differences. We conjecture the time paths needed for forming the firms' value functions, which are inputs in iterating backwards from the final steady state. We then iterate forwards on the laws of motion for the relative qualities of the two countries, solve the households' problems, check the distances from the equilibrium conditions being satisfied and update accordingly until convergence. More details are given in the Appendix C.

Optimal subsidies. The theoretical insights in Section 3.5 guide the interpretation of our findings. The optimal non-cooperative subsidies equilibrium results from a two-stage policy game between the two regions: in the first stage governments set their subsidies and in the second stage firms choose R&D and production to maximize their profits, and households choose their utility-maximizing consumption bundles and asset holdings. For each level of the other region's subsidy, policy makers set their subsidy according to their best-response functions,

$$s_n^W(s_n^E) = \arg\max \left\{U^W(s_n^W, s_n^E)\right\}, \quad s_n^E(s_n^W) = \arg\max \left\{U^E(s_n^W, s_n^E)\right\}.$$

For the two cooperation scenarios, a global policy maker solves

$$(s_h^W, s_h^E) = \arg\max \left\{U^{EU}(s_h^W, s_h^E)\right\}, \text{ and } s_{uni} = \arg\max \left\{U^{EU}(s_{uni})\right\}$$

in the case of the harmonised and unified subsidy, respectively, where $U^{EU} = U^W + U^E$ is the union welfare.

The policy game yields the Nash equilibrium subsidies shown in Figure 4, where we plot the best response functions for the steady state; in Table 4, we also report the subsidies obtained taking into account the transitional dynamics. The best response functions show the presence of policy complementarity where an increases in the subsidy by one region triggers a subsidy hike by the other. This complementarity is sustained by the strategic motive discussed in Section 3.5. The possibility of dumping part of the business stealing effect of innovation onto the other region and of shifting profits across borders pushes countries to a policy competition, resulting in a 'race to the top' to subsidise national firms which leads to extremely high steady-state Nash subsidies.

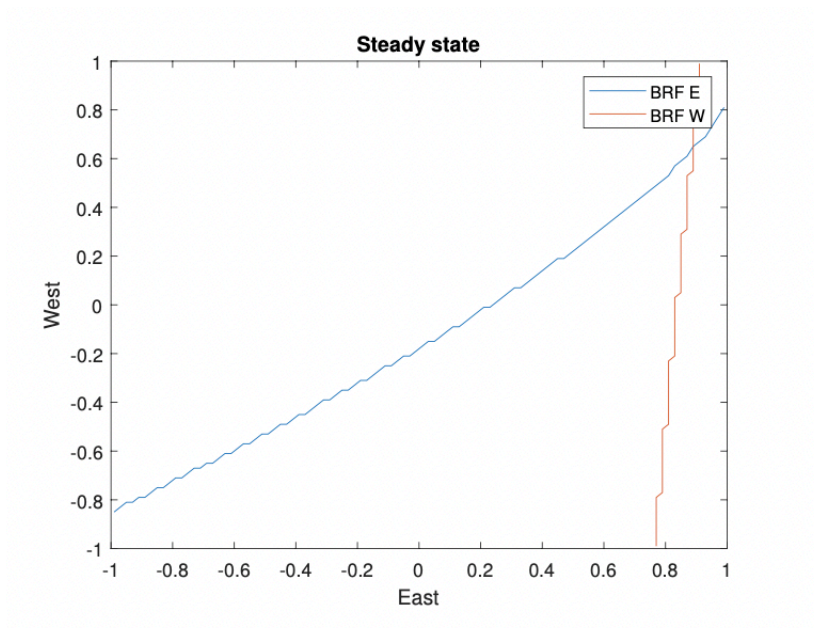


Figure 4: Best response functions in steady state

In Schumpeterian models, the optimal R&D subsidy can be positive or negative depending on the relative strength of opposite external effects. Business stealing motivates R&D taxes, while it is tamed and possibly offset by the strategic motive. The consumer surplus and intertemporal knowledge spillovers channels further motivate subsidies. In our benchmark economy, the Nash subsidies are positive, suggesting that the positive innovation externalities (consumer surplus and intertemporal spillovers) and the strategic motive dominate the business stealing externality, thereby leading governments to subsidise innovation.

While the Nash subsidies are very large and higher for the East than the West, accounting for the transition yields smaller, and more reasonable, values with the West obtaining higher policy incentives. The higher Western subsidies results from its higher innovation efficiency and the local bias in knowledge spillovers ($\beta = 0.6$). Recall that in benchmark economy, most industries have a Western leader ($\omega^W = 0.91$), so that the aggregate quality Q^W is substantially larger than Q^E and therefore knowledge spillovers in the R&D technology (8) are stronger for Western firms. When the analysis is confined to the steady state, the result is flipped: not accounting for the transitional growth effects drives policy makers to offer stronger incentives in the country where innovation is less efficient.

Table 4: Cooperative vs. non-cooperative R&D subsidies

	Transition			**Steady State**		
	s^W	s^E		s^W	s^E	g
Optimal subsidies						
Observed (s_o^W, s_o^E)	0.12	0.10		0.12	0.10	0.006
Nash (s_n^W, s_n^E)	0.55	0.47		0.65	0.89	0.006
Harmonised (s_{har})	-0.39	0.59		-0.99	0.55	0.006
Union (s_{uni})	0.49	0.49		-0.99	-0.99	0.006
Welfare gains	W	E	W+E	W	E	W+E
Harmonised vs Nash	-0.08	0.25	0.17	0.03	0.32	0.35
strategic motive	0.07	0.41	0.48	0.08	0.37	0.45
consumer surplus	-0.07	-0.06	-0.12	-0.05	-0.05	-0.10
intertemporal spillovers	-0.10	-0.10	-0.20	0.00	0.00	0.00
Harmonised vs Observed	-0.07	0.23	0.16	-0.09	0.41	0.32
strategic motive	0.02	0.32	0.34	0.02	0.51	0.53
consumer surplus	-0.06	-0.06	-0.12	-0.11	-0.11	-0.22
intertemporal spillovers	-0.03	-0.03	-0.06	0.00	0.00	0.00
Union vs Nash	-0.00	0.04	0.04	0.14	-0.06	0.08
strategic motive	0.01	0.06	0.07	0.08	-0.12	-0.04
consumer surplus	-0.00	-0.00	-0.00	0.06	0.06	0.12
intertemporal spillovers	-0.01	-0.01	-0.02	0.00	0.00	0.00
Union vs Observed	0.01	0.02	0.03	0.02	0.03	0.05
strategic motive	-0.04	-0.04	-0.08	0.02	0.03	0.05
consumer surplus	-0.01	-0.01	-0.02	0.00	0.00	0.00
intertemporal spillovers	0.06	0.06	0.12	0.00	0.00	0.00

Notes. All welfare effects are in compensating variation as (23) with $T = \infty$.

We now present the two cooperation scenarios, starting with harmonised subsidies. We find that the global policy maker wants to tax R&D in the West and subsidise it in the East above the Nash level. Taxing the region that accounts for most of global R&D, cooperation aims at reducing the public incentives to R&D globally by cutting the average innovation subsidy in the union.[34] Thus, there is too much innovation in the global economy. Our theoretical insights suggest that cooperative policy wants to curb innovation when the strategic motive for subsidies is stronger than to positive innovation externalities and drives the non-cooperative policy. The difference between the cooperative subsidy in the two regions is also driven by the diversification channel. The negative local R&D externality is very strong in our baseline calibration, $\alpha = 0.2$, hence, the policy maker has strong incentives to subsidise innovation in the East and discourage it in the West. Local decreasing returns to R&D induce the global policy maker to promote geographical diversification rather than concentration.

In the second cooperation scenario, we look for the globally optimal unified subsidy, which turns out to be positive for both countries and smaller than Nash for the West but larger for the East. As in the previous scenario, cutting the subsidy to the most innovative country signals that there is too much innovation in the global economy. Hence, the main driver of cooperation via unified subsidy is again the internalisation of the strategic motive. Differently from the harmonisation case though, now the policy maker has access to only one instrument and cannot allocate policy incentives according to the specialisation/diversification trade off.

It is important to notice that optimal subsidies, both cooperative and non-cooperative, are quite different when obtained considering the transitional dynamics instead of focusing only on the steady state. Later we will see that the welfare impact of cooperation will also be quite different. The reason for this difference is that the economy's transition generated by a change in subsidies is slow and non-linear. This is illustrated in Figure D.1, where we plot the response of real income to a move from the observed to the harmonised subsidies.[35] Our results highlight the importance of including the transitional dynamics when performing optimal policy analysis in growth models.

Welfare gains from cooperation. Turning to the welfare impact of different policy scenarios, we report the effects of cooperation in terms of compensating variation. If cooperation is implemented at time 0 and is a permanent policy change, the compensating variation χ is the change in real consumption such that,

$$\int_0^T e^{-(\rho-n)t} \log\left(\frac{c_{co}^K(t)}{P_{co}^K(t)}\right) dt = \int_0^T e^{-(\rho-n)t} \log\left((1+\chi)\frac{c_{no}^K(t)}{P_{no}^K(t)}\right) dt, \tag{23}$$

where T is the horizon of the policy evaluation. Households in the non cooperation scenarios (Nash and observed subsidies) would need to receive χ additional consumption for each period between

[34] Recall that in the calibration 91% of sectors are led by Western firms.

[35] Most quantitative analysis of optimal innovation policy is performed focusing on the steady state. See Acemoglu et al. (2018) for a closed economy analysis and Impullitti (2010) for the open economy. One exception is Akcigit et al. (2018b) which studies the welfare impact of R&D subsidies in open economy accounting for the transitional dynamics.

0 and T in order to be as well off as in the cooperation scenarios. The analysis of the transitional dynamics allows us to consider both short, medium and very long policy horizons. We first present the results with infinite policy horizon then we explore shorter horizons.[36]

In Table 4, we present the steady state gains along with transitional dynamics results for $T = \infty$. The harmonised policy produces a substantial welfare gain with respect to the Nash scenario: global welfare increases by 35% when comparing steady states and by 17% when accounting for the transition. The gains are similar when computed with respect to the observed subsidies. The welfare decomposition suggests that the gains from cooperation for the economic union as a whole derive from the internalisation of the strategic motive. This confirms the intuition provided above arising from the comparison between Nash and cooperative subsidies. The diversification channel plays a role as well: by reallocating R&D incentives toward the country that innovates less the planner increases R&D efficiency thereby reducing the amount of labor resources needed for innovation and increasing production and consumption.

Interestingly, no gain comes from internalising knowledge spillovers. The global policy maker pushes Western firms to innovate less than in the Nash scenario, taxing their R&D and does the opposite with the Eastern firms. By forcing the most R&D efficient country to innovate less, cooperation slows down global growth, as shown more clearly below, thereby generating losses via the positive innovation externalities, consumer surplus and spillovers which are common to both regions.[37] In other words, cooperation reduces the weighted average global subsidy, as it taxes the region doing most of the innovation, because there is too much innovation in the global economy in the Nash scenario. Too much global innovation is due to the strategic motive which cooperation corrects and is therefore the source of the welfare gains from this policy. These gains are concentrated in the East, while the West actually loses from cooperation. This happens because the tax of Western R&D reallocates market shares and profits toward Eastern firms, thereby generating a larger gains via the strategic motive for the latter. For the West then, these gains are not large enough to compensate for the losses due to lower growth, thereby leading to an overall welfare loss.

Figure 5a shows the transitional dynamics of growth to the policy changes. Precisely, it shows the deviation from the growth path of the economy under observed subsidies, produced by moving to the harmonised scenario. It reports both aggregate growth, the growth rate of aggregate quality Q, and its two components, the quality in sectors with western and eastern leaders, Q^W and Q^E. Aggregate growth under the cooperative subsidies is below its baseline path for many years along the transition to the steady state. The result is driven by a drop in growth of Western-led industries, induced by the R&D tax, offsetting the growth in Eastern-led industries, induced by their subsidy. The changes in the West dominate since it holds the majority of the market share in the calibration. The semi-endogenous nature of the model implies that growth converges back to its exogenous long-run value as the economy

[36] The optimal subsidies given in Table 4 are found from maximising welfare over the infinite horizon: $T = \infty$.

[37] While the growth rate of global quality $g(t)$ and therefore the gains from intertemporal spillovers are the same for both countries, the geographical component of the price index $\bar{P}^K$ and therefore the consumer surplus channel, in general, differs across countries due to the trade cost. In our baseline calibration the trade cost is zero, hence the difference disappears.

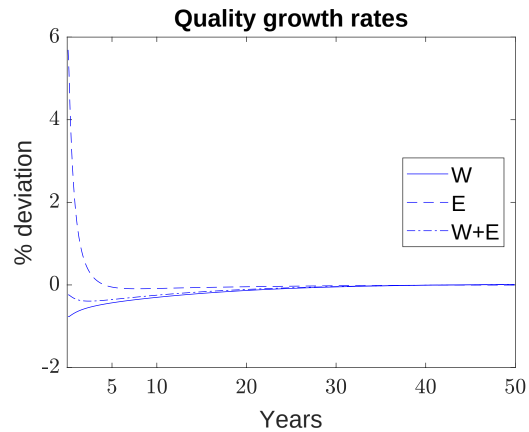
reverts back to the steady state.

Next, we explore the impact of the policy maker horizon on the gains from cooperation. Figure 5b shows the that the cooperative subsidies are slightly increasing with the horizon for the East and sharply decreasing for the West. Interestingly for a 5-year horizon, both subsidies are positive and close the their Nash counterparts. In this scenario, no country loses from cooperation (figure 5c). Moreover, the gains are still driven by the internalisation of the strategic motive but there is no loss from the spillover channel (5d). For longer horizons, the results change dramatically. The Western subsidy declines, losses emerge from the intertemporal spillovers channel and the welfare gains of cooperation are only driven by the internalisation of the strategic motive. This result is produced by the semi-endogenous property of our growth model: as in Jones (1995), knowledge spillovers in our R&D technology (7) become weaker ($\phi < 1$) as aggregate quality increases. Consequently, the growth impact of any policy stimulus to innovation weakens as the policy horizon widens. Put differently, the global policy maker exploits subsidies in both countries only for short horizons, as they induce a temporary burst in growth. Policy becomes ineffective at stimulating growth when the horizon is long, and the gains from cooperation derive exclusively from internalising the strategic motive.

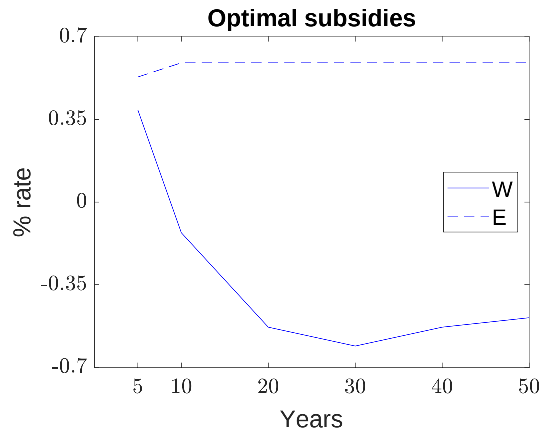
For completeness, the bottom panel of table 4 reports the welfare impact of the unified subsidy. As for the harmonised subsidies, welfare gains from this second cooperation scenario come from internalising the strategic motive. However, the global policy maker is constrained to have only a single policy instrument, meaning that welfare gains must be lower than under the harmonised scenario. Quantitatively, these gains are significantly lower, although, the union scenario is clearly easier to implement politically. Since this scenario is Pareto inferior to harmonisation, we will focus on the latter in the remainder of the paper.

Sensitivity. We analyse the robustness of our main results to local changes in some key parameters of the model. Specifically, the strength of intertemporal knowledge spillovers, ϕ, the parameter controlling the local bias of these spillovers, β, the parameter governing the decreasing returns to R&D, α, and the iceberg trade cost τ. When possible we perform the robustness increasing and decreasing the benchmark value of each parameter by 10%. Since changes in parameters affect both cooperation and Nash subsidies, the cleaner and easier exercise is to focus on the cooperation gains with respect to observed subsidies. We report the gains with respect to Nash as well, for completeness.

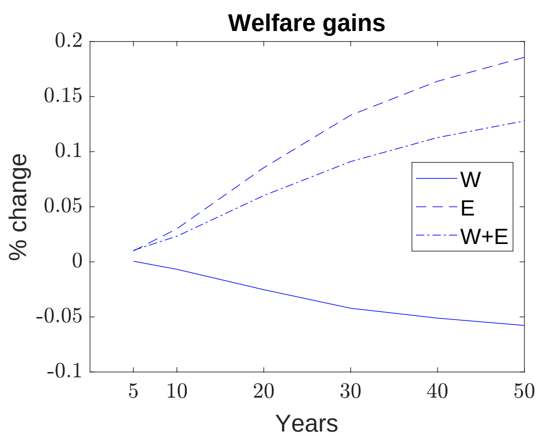
Table F.1 shows that stronger intertemporal knowledge spillovers lead to larger gains from cooperation. In our model the overall degree of increasing returns is $IRS = 1/(\sigma-1)(1-\phi)$. There is little work measuring the degree of increasing returns related to the production of knowledge. Arkolakis et al. (2020), using data on European migration to the US between 1880 and 1920, estimate the overall degree of increasing returns to scale to be between 0.7 and 1.3. Peters (forthcoming), using the settlements of East Germans in West Germany after WWII, finds a value in the same range of 0.89. In our baseline calibration, $IRS = 1/(\sigma-1)(1-\phi) = 1.45$, which is slightly above the upper bound of Arkolakis et al. (2020). In the lower bound of our robustness analysis, we reduce ϕ by 10% and obtain



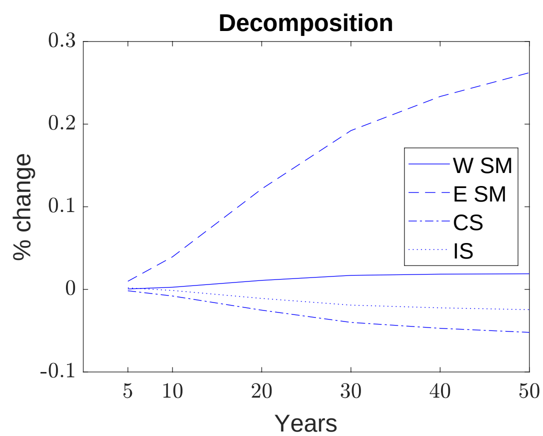
(a) Growth under cooperative subsidies



(b) Cooperative subsidies (policy horizons)



(c) Gains from cooperation (policy horizons)



(d) Gains decomposition (policy horizons)

Figure 5: Growth dynamics and policy maker horizon

Notes: Panel a) shows the transitional dynamics of growth rate of Q, Q^W and Q^E under cooperative subsidies as deviation from the baseline. Panel b) reports the cooperative subsidies for different policy maker horizons. Panels c) and d) show the gains from cooperation and their decomposition for different policy horizons.

$IRS = 1.2$, which is within the available estimates. The gains from cooperation decline slightly, from 16% in the benchmark to 15.1%, which is still a substantial welfare improvement. A similar decline is found in the gains with respect to the Nash subsidies.

Table F.2 suggests that when knowledge spillovers become more global, which happens for lower values of β, the gains from cooperation with respect to the observed subsidies are smaller. Intuitively, since cooperation gains in our framework derive from correcting the strategic motive while the spillover channel produces only losses, when spillovers are more global the losses from cooperation are larger. Reducing the congestion externality, parameter α, does not produce substantial changes to the gains from cooperation versus Nash, while the gains versus observed increase. Finally, increasing the iceberg trade cost from our free trade baseline to 10 and 20% increases the gains from cooperation relative to observed. Higher trade barriers lead to slightly higher Eastern cooperative subsidies and slightly higher Western taxes. Hence, with higher trade barriers, there is more excess growth than in the baseline scenario and the policy maker needs to reduce the incentives to innovate even more.

Taking stock. The policy implication of our findings is then that economic unions, such as the EU, could collect resources from their member states and allocate them centrally and asymmetrically across countries generating substantial benefits for the union as a whole.[38] The weak knowledge spillovers typical of semi-endogenous growth models imply that gains from policy cooperation are driven by internalising the strategic motive for subsidies rather than knowledge spillovers.

Two salient implications emerge from our results. First, growth and the key externality related to it, knowledge spillovers, do not play an important role in shaping the gains from policy cooperation in the long run. This could suggest that a simpler model, perhaps static, as typical in the old strategic trade literature and in the modern quantitative trade theory (e.g. Costinot and Rodríguez-Clare, 2014; Ossa, 2015), with innovation not characterised by intertemporal knowledge spillovers could already have the sufficient ingredients to quantify gains from innovation policy cooperation. Second, there are winners and losers from cooperation and therefore political barriers to its implementation could emerge. In the next sections, we analyse two extensions of the model which allow us to dig deeper into these implications and lead to different conclusions.

5 Foreign direct investment and multinational production

We now incorporate in the model the stylised fact on FDI and innovation presented in Section 2. We assume that Western firms, upon a successful innovation, can decide to offshore production to the East if profitable. The technology gap related to the difference in innovation efficiency produces a difference in market leadership and labor costs, which give Western firms the incentive to offshore production to the East. Offshoring production requires that firms devote resources to adapt/transfer

[38] This is broadly speaking the intentions of the Framework Program and especially of the Structural and Investment Funds.

their technology abroad. We call this activity *adaptive R&D* or *FDI*, to distinguish from the research efforts devoted to improve product qualities. We refer to the newly established firms through offshoring as Western multinationals. The key feature of FDI is that it is a vehicle of cross-border knowledge spillovers, where ideas flow across countries via *endogenous international spillovers*. We assume that when western firms move production to the East, the stock of knowledge capital in the East increases, thereby rising the R&D productivity of potential Eastern entrants. This generates a positive relationship between FDI and innovation in the East, in line with the empirical evidence in Table 1 and 2.

Innovation. The innovation technology is the same as (7) but the specification of the knowledge spillovers (8) changes. We keep the assumption that there is a local bias for spillovers and that R&D is more productive in the West, that is, γ is higher. This implies that, as in the benchmark model, the West is the high wage country and the FDI flow will only go from West to East, which is also the empirically relevant case. Formally,

$$\begin{aligned} A^W(\omega,t) &= \gamma^W \left(\frac{q(\omega,t)}{\hat{Q}^W(t)^{\phi}} \right)^{-1} \quad \text{for } \omega \in \omega^W, \\ A^M(\omega,t) &= \gamma^M \left(\frac{q(\omega,t)}{\hat{Q}^W(t)^{\phi}} \right)^{-1} \quad \text{for } \omega \in \omega^M, \\ A^E(\omega,t) &= \gamma^E \left(\frac{q(\omega,t)}{\hat{Q}^E(t)^{\phi}} \right)^{-1} \quad \text{for } \omega \in \omega^E. \end{aligned} \tag{24}$$

where ω^W is the set of sectors with Western leader producing in the West, ω^M is the set of industries with Western leader offshoring production to the East, ω^E is the set of sectors with an Eastern leader.[39] The stock of knowledge carrying the spillovers is $\hat{Q}^W(t) = Q^W(t)^{\beta^W} Q(t)^{(1-\beta^W)}$, $\hat{Q}^E(t) = Q^{E+M}(t)^{\beta^E} Q(t)^{(1-\beta^E)}$ and $0.5 < \beta^k < 1$. Q^K, for $k = W,E,M$ are the average quality of these three types of sectors. $Q^W(t) = \int_{\omega^W} q(\omega,t)d\omega$ is the average quality of sectors with Western leader producing in the West, $Q^{E+M}(t) = \int_{\omega^E+\omega^M} q(\omega,t)d\omega$, is the average quality of sectors with production in the East from both Eastern leaders and multinational firms. The technology in (24) implies that firms investing in innovation to enter sectors where the leader is a western multinational enjoy the same level of spillovers as western firms. Moreover, the presence of FDI improves eastern innovation efficiency in the sectors where eastern firms are leaders. The key element of this augmented framework is that FDI endogenises international knowledge spillovers.

As in the benchmark model, free entry pins down equilibrium innovation and FDI choice. In order to highlight the differences with the baseline model, here we report the steady state free entry conditions, which are slightly easier to interpret:

[39] For completeness we could also include a type of sectors with Eastern leader that have not had FDI before. That is, sectors that have managed to become global leaders without any spillovers from the more advanced Western firms. Unfortunately, it is not possible to find statistics to discipline this type of sectors, so we do not include them.

$$
\begin{aligned}
1-s^W &= \frac{\pi^W(1)}{\rho+I^W+\phi g} MPR(I^W) && \text{for } \omega \in \omega^W, \\
(1-s^E)w^E &= \frac{\pi^E(w^E)}{\rho+I^W+I^E+\phi g} MPR(I^E) && \text{for } \omega \in \omega^E, \\
(1-s^M)w^E &= \left(\frac{\pi^M(w^E)}{\rho+I^W+I^E+\phi g} - \frac{\pi^W(1)}{\rho+I^W+\phi g}\right) MPR(I^M) && \text{for } \omega \in \omega^M, \qquad (25)
\end{aligned}
$$

where $MPR^K(\omega) = A^K(\omega,t)\left(I^K(\omega,t)\right)^{\frac{\alpha}{\alpha-1}}$ is the marginal productivity of research for country K in sector ω. The government in the West subsidises both innovative R&D at the rate s^W and the adaptive research (FDI) needed to transfer technology abroad at a potentially different rate s^M.

To provide intuition we do not report the cumbersome expressions for equilibrium profits and we just highlight the key differences in labor cost between production in the West which costs $w^W = 1$ and production in the East at cost w^E. The first two conditions are similar to those in the benchmark model, with the value of the firm expressed as profit discounted with the interest rate and creative destruction. The novel expression is the free entry into FDI, the third condition, where firms compare the value of producing at home with the value of offshoring production. The key endogenous variables affecting the decision of offshoring are the difference in labor cost between the two locations, the *wage gap*, and the difference in innovation determined by I^W and I^E, the *creative destruction gap*. Higher innovation in the East reduces the creative destruction gap which implies an increase in the risk of being copied and technologically leapfrogged for western firms and therefore a lower incentive to offshore production.

Our framework thus adds a dynamic margin to the static choice of multinational production typical of trade models, where the decision is only driven by the gap in production cost (e.g. Arkolakis et al., 2018). Moreover, it extends the product cycle model in Helpman (1993) and the versions with FDI and multinationals in (e.g. Dinopoulos and Segerstrom, 2010), allowing the poorer country to innovate and not just simply copy the foreign technology infringing intellectual property rights. Finally, and more saliently, it incorporates ideas flow brought via FDI as a key driver of international knowledge spillovers.

FDI, knowledge spillovers and the motive for subsidies. How does FDI impact the motives to set R&D subsidies cooperatively? Technology (24), carries two new distortions that the global policy maker wants to correct. First, Western firms' underinvestment in innovation due to international knowledge spillovers is stronger than in the baseline model. Due to FDI, eastern firms enjoy stronger spillovers, as they have access to larger chunk of the advanced region's stock of knowledge. Through this margin, the presence of FDI produces an additional reason for the global policy maker to subsidise Western innovation. In addition to this, FDI's role of carrying knowledge spillovers across borders implies that there is underinvestment in adaptive R&D from a global perspective. This second margin implies that the cooperation policy should also include a new instrument, a subsidy to FDI.

Growth. The second important difference with the baseline model is that the steady state growth rate changes reflecting the more sophisticated sectoral structure. Average quality $Q(t)$ evolves due to innovation performed in the West and in the two types of sectors in the East,

$$\frac{\dot{Q}(t)}{Q(t)} = (\lambda^{\sigma-1} - 1)\left[I^W(t) + \left(q^E(t) + q^M(t)\right) I^E(t)\right] = g(t). \tag{26}$$

where $q^W + q^E + q^M = 1$ and the relative qualities of the three sectors, $q^k = Q^k/Q$. Since adaptive R&D from multinational firms does not directly generate innovation, the drivers of aggregate quality growth are the innovation by western leaders I^W, which takes place in all sectors of the economy, and innovation by eastern leaders, I^E, taking place in the sectors with Eastern leaders and where leaders are Western FDI, $\omega^M + \omega^E$. Adaptive R&D affects growth only indirectly via the share of sectors where a part of the eastern innovation occurs. Again, the growth rate of the average quality (g) pins down the growth rate of the global economy. As in the baseline model, it can be shown that the steady state growth rate is exogenous and pinned down by population growth, $g = n/(1-\phi)$. Thus in our setup, like any other policy, FDI does not affect the steady-state growth rate.

5.1 Quantitative analysis

We need to recalibrate the model to discipline the new parameters. There is one new innovation efficiency parameter γ^M. We also allow manufacturing productivity in M-type sectors to be different from E-types, so that we now have thee productivity parameters, a^k for $k = W, E, M$. For lack of data targets we assume $s^M = 0$ in the baseline parametrisation. We assume that the parameter governing the local nature of R&D spillovers is the same for all sectors and regions, that is, $\beta^k = \beta$. The new key parameter to discipline is that governing innovation efficiency in adaptive R&D, γ^M, which contributes to the distribution of leadership.

As in the benchmark model, we use the calculated share of sectors with Western leadership in the EU28 economy (91%) that we obtained from the OECD AMNE database for the 2005-2016 period. Furthermore, we calculate the total share of industries with Eastern leadership (ω^E) as the share of output of Eastern-owned firms in the East in the total EU28 output which amounts to 7% of the EU economy. The residual $(1 - \omega^W - \omega^E)$ represents the share of industries with multinational subsidiary firms production in the East (2%).

Table 5 reports the model fit, the parameters values are in the appendix (Table E.1).

Optimal policy with FDI. In table 6, we report the harmonised R&D subsidies and the gains from this cooperation scenario with respect to the observed subsidies.[40] As in our benchmark economy, the harmonised subsidies bring substantial gains for the union as a whole, but four key differences emerge.

[40] We focus on the gains with respect to the observed subsidies because the numerical solutions to the dynamic Nash subsidies of this more complex framework are less stable and robust.

Table 5: Moments (FDI extension)

Moments	Data (Model)	Source
East relative wage (w^E)	0.60 (0.56)	Eurostat, 2015
MFP growth rate	0.66% (0.66%)	OECD 2005-2016
Share of sectors, Western leadership (ω^W)	91% (91%)	OECD, 2005-2016
Share of sectors, Eastern leadership (ω^E)	7% (5%)	OECD, 2005-2016
Share of sectors, MNE leadership (ω^M)	2% (4%)	OECD, 2005-2016
West R&D expenditure/GDP	3.87% (3.13%)	Eurostat, 2015
East R&D expenditure/GDP	2.12% (2.00%)	Eurostat, 2015
West share of labour in R&D	3.13% (4.54%)	Eurostat, 2015
East share of labour in R&D	2.22% (5.18%)	Eurostat, 2015
West innovation elasticity to subsidy	[1.2, 2.9] (1.28)	Akcigit et al. (2018)
East innovation elasticity to subsidy	[1.2, 2.9] (1.43)	Akcigit et al. (2018)

First, the sign of the harmonised subsidies is flipped: the global policy maker wants to subsidise Western firms' innovation and tax Eastern firms'. Second, the gains from cooperation are driven by the growth engine of the economy, intertemporal knowledge spillovers. Third, the cooperation gains are decreasing in the cost of FDI. Fourth, all regions gain from cooperation.

The insight for the first difference operates via the diversification channel. FDI carries technology spillovers across space, which makes Western innovation much more valuable for the union as a whole. According to technology (24), firms innovating in sectors led by a Western multinational receive the same knowledge spillovers as Western firms. Moreover, past FDI makes innovation by Eastern firms in industries led by an Eastern incumbent more productive via higher spillovers as well. The large cooperation subsidy for the West and the large tax for the East reflect this new asymmetry. As such, the efficiency cost of concentrating R&D where it has a higher productivity (higher γ) is lower and more than compensated by the gains.

Why are the gains from cooperation now driven by the internalisation of intertemporal knowledge spillovers? FDI strengthens knowledge spillovers, relative to the baseline, to such an extent that the gains from temporary stimulating growth outweigh those from the mitigation of the distortions produced by the strategic motive for subsidies. Western firms do not take these spillovers into account, producing an under-investment innovation from a global perspective. This also implies that the gains from innovation policy cooperation are larger under FDI. Recalibrating the model means this cannot be seen immediately by comparing these gains to those from the baseline. This result can instead be seen looking at the intensive margin of FDI. That is — studying the impact of a reduction in the cost of transferring the technology abroad, the cost of FDI. Table 6 reports the impact of doubling and tripling the FDI efficiency. A higher value of parameter γ^M implies a higher efficiency of adaptive R&D, more FDI, stronger international knowledge spillovers and therefore higher gains from cooperation via the spillover channel.

The last key difference is that, while in the baseline economy cooperation weakly benefits both

Table 6: FDI costs and policy cooperation

	$\gamma^M = 0.25$			$\gamma^M = 0.5$			$\gamma^M = 0.75$		
	s^W	s^E	s^M	s^W	s^E	s^M	s^W	s^E	s^M
Observed (s_o^W, s_o^E)	0.122	0.097	0.000						
Harmonised (s_{har})	0.330	-0.990	0.000	0.370	-0.990	0.000	0.430	-0.990	0.000
Welfare gains	W	E	W+E	W	E	W+E	W	E	W+E
Harmonised vs Observed (CEV)	0.053	0.022	0.075	0.054	0.033	0.087	0.055	0.042	0.097
strategic motive	-0.012	-0.043	-0.055	-0.017	-0.038	-0.055	-0.026	-0.039	-0.065
consumer surplus	0.000	0.000	0.000	-0.002	-0.002	-0.004	-0.003	-0.003	-0.006
intertemporal spillovers	0.065	0.065	0.131	0.073	0.073	0.146	0.084	0.084	0.168

Notes. All calculations take the transitional dynamics into account and the welfare effects are in compensating variation as (23) with $T = \infty$, $\gamma^M = 0.25$ is the baseline calibration. The FDI subsidy is kept constant at zero in all scenarios.

regions only with a short policy horizon and damages the West for longer horizons, in the presence of FDI cooperation is mutually beneficial at long horizons as well. In both of these instances, growth is the main driver of cooperation gains. This follows since, in this open economy setup, trade means that the quality level of the consumption basket in each region grows at the same rate. The gains from growth then accrue equally to each country. Consequently, if these gains from growth are sufficiently large that they dominate for one country, they likely will for the other as well. In other words, when international knowledge spillovers are endogenous due to FDI, there is a large underinvestment in innovation and too little growth from a global perspective. By tackling this distortion the policy maker generates gains for both regions.[41]

FDI versus innovation policy. In our analysis we have only focused on policies aimed at tackling the externalities and distortions produced by innovation, while assuming that the adaptive R&D needed to transfer production abroad did not receive any government support. The knowledge spillovers carried by FDI across the border are not accounted for by Western firms when making their offshoring decision. We now turn to study the standard *innovation policy*, the R&D subsidy, in conjunction with an FDI subsidy. The latter can be seen as a more standard tool of *trade policy*, as it affects the cost of multinational activity without direct implications for innovation.[42] With a few exceptions (e.g. Akcigit et al., 2018b) innovation and trade policies are typically analysed separately, in different models. Our framework allows a joint analysis and permits a decomposition of the their specific contribution to the welfare gains from international policy cooperation.

[41] The optimal subsidies, the gains from cooperation and their decomposition for different policy horizons are reported in figure D.2

[42] Recall that adaptive R&D does not have any impact on innovation and growth.

In Table 7, the first column reports the gains from cooperation with respect to the observed subsidies in the model with FDI, where FDI is not subsidised, these are the baseline results in Table 6. The second column reports the gains from jointly choosing both R&D and FDI subsidies cooperatively. The third column presents the gains from choosing only FDI subsidy cooperatively, while leaving the innovation subsidies at their observed level. Two results emerge. First, the gains from cooperation are larger for both regions when both R&D and FDI subsidies are chosen cooperatively. Second, the total gains from cooperation in FDI subsidies are similar to those in R&D subsidies and they are both driven by internalising intertemporal spillovers.

The first result follows by design in the qualitative sense — FDI brings externalities that are separate from those created by innovation (those discussed in section 3.5) — an extra policy instrument to correct them can only give larger welfare gains. The model sheds light on the large quantitative effect of using these instruments jointly — almost doubling the gains from using the R&D subsidy alone. Notice also that the cooperative subsidy in the West is substantially smaller when the policy maker can subsidise FDI than when solely subsidising innovation. This suggests the presence of a policy complementarity: stronger technology diffusion reduces the underinvestment in innovation by increasing the efficiency of R&D technology in the East and therefore the need for policy support to directly stimulate innovation.[43]

Given that FDI does not directly contribute to growth, the 6% welfare gain its subsidisation gives is perhaps surprising. The decomposition indicates that a large part of these gains, 4.4% of consumption, come from internalising the impact of FDI on intertemporal spillovers. This highlights the importance of accounting for growth and dynamics when modelling FDI. Using a static model and focusing only on the strategic motive would only capture roughly half of the associated welfare gains.

Taking stock. Extending the baseline semi-endogenous growth model to endogenous idea flows via FDI leads to substantially different results. The growth engine of the economy, knowledge spillovers, become the key driver of the gains from innovation policy cooperation, which benefits both regions. Lower FDI costs lead to higher gains from innovation policy cooperation. Moreover, due to its impact on international knowledge spillovers, FDI provides an additional motive for subsidy cooperation leading to gains that are quantitatively similar to those of R&D subsidies.

6 Fully endogenous growth

In this section, we show that in a fully-endogenous version of our Schumpeterian model, even abstracting from endogenous knowledge flows via FDI, knowledge spillovers, are again the key driver of the gains from innovation policy cooperation.

[43] This mimics the results in 6, where we show that lower cost of FDI leads to lower optimal subsidy in the West.

Table 7: Gains from cooperation: R&D vs. FDI subsidies

	(1) R&D subs. only	(2) R&D+FDI subs.	(3) FDI subs. only
s^W	0.330	0.177	0.122
s^E	-0.990	-0.990	0.097
s^M	0.000	0.888	0.908
West	0.053	0.055	0.018
strategic motive	-0.012	-0.002	0.001
consumer surplus	0.000	-0.014	-0.005
intertemporal spillovers	0.065	0.070	0.022
East	0.022	0.077	0.045
strategic motive	-0.043	0.020	0.028
consumer surplus	0.000	-0.014	-0.005
intertemporal spillovers	0.065	0.070	0.022
West + East	0.076	0.132	0.063
strategic motive	-0.055	0.018	0.029
consumer surplus	0.000	-0.028	-0.010
intertemporal spillovers	0.131	0.140	0.044

Notes. Column (1) reports the gains from cooperation in the model with FDI, where the FDI subsidy is zero. Column (2) reports the gains when both R&D and FDI subsidies are set cooperatively. Column (3) reports the gains when only FDI subsidies are set cooperatively and R&D subsidies in both regions are kept at the observed level. All gains are computed with respect to observed subsidies and accounting for the transitional dynamics.

The R&D technology. The key feature of the semi-endogenous solution to the scale effect problem is that it leads to models where growth is essentially exogenous in the long run.[44] The second solution to the scale effect problem that emerged in the literature preserves the endogeneity of long-run growth. The key idea is that a rise in the scale of the economy increases the number of products in the same proportion. Since growth depends on the amount of researchers per product line, the increase in the number of products 'dilutes' the impact of population growth, and of growth in the number of researches, leaving the amount of researchers per product invariant (e.g. see Peretto, 1998; Dinopoulos and Thompson, 1998; Howitt, 1999).

A simple way to incorporate this solution in our model, where the number of products is constant, is to make innovation efficiency decreasing with the scale of population (Dinopoulos and Thompson, 1998). Formally, we must set the spillover parameter ϕ in (7) to one and introduce a difficulty index of R&D that increases with population size. This leads to the following R&D technology,

$$I_i^K(\omega,t) = A^K(\omega,t)^{1-\alpha} \frac{l_{Ri}^K(\omega,t)}{X(\omega,t)} \left(\frac{L_R^K(\omega,t)}{X(\omega,t)} \right)^{-\alpha}, \tag{27}$$

where $X(\omega,t) > 0$ measures the degree of complexity in the invention of the next quality product in industry ω and all the rest is the same as in (7). We assume that the technological complexity index is

$$X(\omega,t) = 2\kappa L(t), \tag{28}$$

where κ is a positive constant and $L(t)$ is the total population size, thereby formalising the idea that it is harder to innovate in a more crowded global market. The rest of the model is unchanged, in particular the growth rate is still as in (15) outside the steady state and preserves the same structure in steady state, $g = (\lambda^{\sigma-1} - 1)[I^W + I^E]$, but this time the innovation rates in the two regions are endogenous and respond to policy.

Optimal policy. We calibrate this version matching the same targets as in the baseline model, the resulting parameter values and the model fit are in Table E.2. Here we focus on the harmonisation subsidies and the related welfare implications relative to the observed rates. Table 8 presents the results. The harmonised subsidies are positive and high for both regions. Compared to results in the baseline model, the substantial difference that we highlight is that growth is the key source of the gains from policy cooperation, with intertemporal spillovers contributing positively and substantially more than the other channels.

The interpretation of these results is fairly straightforward. In fully-endogenous models, knowledge spillovers are strong and subsidies have persistent effects on growth. Thus, there is larger underinvestment in innovation both for each country taken separately and for the union as a whole. Both local and

[44] If population growth is endogenous then this statement is not necessarily true anymore (see e.g. Jones, 2022). Moreover, Cozzi (1997) shows that if spillovers, and therefore the growth potentials, are heterogeneous across sectors, policy can affect long-run growth even in a semi-endogenous model.

global knowledge spillovers are stronger, thus the key goal of global policy cooperation is to internalise this externality. Consequently. the key source of gains from cooperation is the spillover channel.

Table 8: Optimal R&D subsidy scenarios: endogenous growth

	Transition Included			**Steady State Only**		
	s^W	s^E		s^W	s^E	
Observed (s_o^W, s_o^E)	0.122	0.097		0.122	0.097	
Harmonised (s_{har})	0.830	0.830		0.830	0.830	
Welfare gains	W	E	W+E	W	E	W+E
Harmonised vs Observed (CEV)	0.070	0.068	0.138	0.071	0.069	0.140
strategic motive	-0.151	-0.153	-0.304	-0.153	-0.156	-0.309
consumer surplus	0.000	0.000	0.000	0.000	0.006	0.012
intertemporal spillovers	0.221	0.221	0.442	0.224	0.224	0.448

Notes. The welfare gains including the transitional dynamics are for the long run policy horizon, $T = \infty$.

Both regions gain from the higher subsidies and higher growth, produced by the cooperation scenario, via the spillover channel. As in the semi-endogenous model with FDI, both regions gain even with long policy horizon. In the baseline model instead, mutual gains are attainable only with short policy horizons.[45]

7 Conclusion

Motivated by the current debate on further integration in the European Union, this paper provides a framework to analyse innovation policy cooperation among countries closely integrated via trade and FDI. The analysis singles out the key distortions motivating cooperation and studies their role in shaping the gains of policy coordination.

Endogenous growth models are a natural choice for the analysis of innovation policies and knowledge spillovers are the source of growth in these frameworks. Our results show that these spillovers and their geographic distribution are crucial in shaping the gains from cooperation. When they are too weak to sustain growth in the long run and they are locally concentrated, the benefits of cooperation results exclusively from internalising the strategic motive for subsidising innovation. That is, using policy to shift profits across regional borders, which results in a zero-sum game that cooperative policy wants to discourage. When the geographic concentration of spillovers is endogenised via FDI flows,

[45] Introducing FDI into the fully endogenous framework has the similar implications to those seen for the baseline model. The gains from cooperation are even more strongly driven by knowledge spillovers and are increasing with the volume of FDI. We do not report the results of this extension for brevity, but they are available upon request.

the opposite attains and internalising these spillovers becomes the key driver of cooperation. A similar outcome emerges when spillovers are strong enough so that long-run growth is endogenous and can be affected by policies.

Surprisingly, the strong policy interest on the topic analysed in this paper is not matched by available research. Ours is a first step toward a macroeconomic analysis of innovation policy cooperation and is amenable to many extensions and further analysis. We kept the framework simple, minimising the departure from standard models. Perhaps the first item on the list of future work is to introduce a third country to study how trade diversion can impact the results. Another interesting extension would involve casting the analysis in recent quantitative growth models where firm heterogeneity allows a direct contact with micro data (e.g. Akcigit et al., 2018b). Selection margins could produce new channels through which the gains from cooperation operate. Finally, more empirical research is needed on knowledge spillovers to obtain better measures of their size, which pins down the size of increasing returns to scale in these models. Knowing its value is fundamental for the source and size of the gains from cooperation, but also for many other key questions in the growth literature (see e.g. Jones, forthcoming).

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Online Appendix

A Robustness on firm-level estimations

Table A.1: Domestic firms reporting innovation and foreign firms by region-sector Robustness

Dependent variable: Dummy variable for domestic firms reporting innovation				
Explanatory variable	dummy (1)	count (2)	dummy (3)	count (4)
	Manufacturing		Service	
Foreign presence	0.034**	0.021***	0.023	0.007**
	(0.013)	(0.004)	(0.019)	(0.003)
Observations	4,612	4,612	6,853	6,853
R-squared	0.234	0.234	0.219	0.219
	Private firms		State-owned firms	
Foreign presence	0.035***	0.012***	-0.019	-0.019
	(0.013)	(0.003)	(0.176)	(0.176)
Observations	11,328	11,328	96	96
R-squared	0.207	0.207	0.686	0.686
	Sales above median		Sales below median	
Foreign presence	0.044**	0.012**	0.030**	0.013***
	(0.018)	(0.005)	(0.014)	(0.003)
Observations	5,676	5,676	5,602	5,602
R-squared	0.219	0.218	0.221	0.222
	Exporters		Non-exporters	
Foreign presence	0.038**	0.014*	0.032*	0.009**
	(0.018)	(0.007)	(0.017)	(0.003)
Observations	2,516	2,516	8,941	8,941
R-squared	0.236	0.236	0.209	0.209
	Importers		Non-importers	
Foreign presence	0.035	0.031**	0.027*	0.008**
	(0.023)	(0.013)	(0.015)	(0.003)
Observations	2,560	2,560	8,903	8,903
R-squared	0.225	0.226	0.203	0.203

All regressions include region, sector and year fixed effects. All regressions include the following firm-level control variables: firms' log of sales, and a set of dummy variables for State-owned enterprises, exporting firms, importing firms. Robust standard error clustered both at the region and at the sector level into brackets. *, **, *** significantly different from 0 at 1%, 5% and 10% level, respectively.

B Model derivations

B.1 Baseline model derivations

B.1.1 Equilibrium conditions

Labor market clearing. Labor demand in the West comes from production in the sectors with western leadership, ω^W, for domestic consumption and export, and also from R&D activities in all sectors. Workers in the East are employed in production activities by firms in sectors ω^E. Like in the West, labor demand for eastern workers comes also from eastern firms' innovation in all sectors of the EU economy.

Substituting (4) and (5) for p^W and p^{*W}, and (8) for $A^W(t)$, we derive the labor market clearing condition in the West as

$$\begin{aligned}
\ell^W &= \int_{\omega^W} a^W q(\omega,t) p^{W(-\sigma)} \frac{c^W \ell^W}{P^W(t)^{1-\sigma}} d\omega + \int_{\omega^W} \tau^W a^W q(\omega,t) p^{*W(-\sigma)} \frac{c^E(1-\ell^W)}{P^E(t)^{1-\sigma}} d\omega + \int_0^1 \frac{I^{W\frac{1}{1-\alpha}}}{A^W(t)L(t)} d\omega \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} a^{W(1-\sigma)} \left(\frac{c^W \ell^W}{P^W(t)^{1-\sigma}} + \frac{c^E(1-\ell^W)}{P^E(t)^{1-\sigma}} \tau^{W(1-\sigma)}\right) \int_{\omega^W} q(\omega,t) d\omega + \frac{I^{W\frac{1}{1-\alpha}}}{\gamma^W} \frac{\int_0^1 q(\omega,t) d\omega}{\hat{Q}^W(t)^\phi L(t)} \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} a^{W(1-\sigma)} q^W \left(\frac{c^W \ell^W}{\bar{P}^W(t)^{1-\sigma}} + \frac{c^E(1-\ell^W)}{\bar{P}^E(t)^{1-\sigma}} \tau^{W(1-\sigma)}\right) + \frac{I^{W\frac{1}{1-\alpha}}}{\gamma^W} \frac{Q(t)}{\hat{Q}^W(t)^\phi L(t)}. \qquad \text{(B.1)}
\end{aligned}$$

where $\ell^W = L^W(t)/(L^W(t)+L^E(t)) = L^W(t)/L(t)$ is the share of total EU labor force in region W, $\bar{P}^{K(1-\sigma)} = P^K(t)^{1-\sigma} Q(t)^{-1}$, $Q(t) = \int_0^1 q(\omega,t)d\omega$, $Q^W(t) = \int_{\omega^W} q(\omega,t)d\omega$ and $q^W = \frac{Q^W(t)}{Q(t)}$. In the East, with $Q^{E(t)} = \int_{\omega^E} q(\omega,t)d\omega$ and $q^E = \frac{Q^E(t)}{Q(t)}$, we obtain

$$\begin{aligned}
1-\ell^W &= \int_{\omega^E} \tau^E a^E q(\omega,t) p^{*E(-\sigma)} \frac{c^W l^W}{P^W(t)^{1-\sigma}} d\omega + \int_{\omega^E} a^E q(\omega,t) p^{E(-\sigma)} \frac{c^E(1-\ell^W)}{P^E(t)^{1-\sigma}} d\omega + \int_0^1 \frac{I^{E\frac{1}{1-\alpha}}}{A^E(t)L(t)} d\omega \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} w^{E(-\sigma)} a^{E(1-\sigma)} \left(\frac{c^W l^W}{P^{W(1-\sigma)}} \tau^{E(1-\sigma)} + \frac{c^E(1-l^W)}{P^{E(1-\sigma)}}\right) \int_{\omega^E} q(\omega,t) d\omega + \frac{I^{E\frac{1}{1-\alpha}}}{\gamma^E} \frac{\int_0^1 q(\omega,t) d\omega}{\hat{Q}^E(t)^\phi L(t)} \\
&= \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} w^{E(-\sigma)} a^{E(1-\sigma)} q^E \left(\frac{c^W l^W}{\bar{P}^{W(1-\sigma)}} \tau^{E(1-\sigma)} + \frac{c^E(1-l^W)}{\bar{P}^{E(1-\sigma)}}\right) + \frac{I^{E\frac{1}{1-\alpha}}}{\gamma^E} \frac{Q(t)}{\hat{Q}^E(t)^\phi L(t)}. \qquad \text{(B.2)}
\end{aligned}$$

Quality aggregates. The average quality index $Q(t)$ equals the sum of the sectoral quality aggretates

$$\begin{aligned}
Q(t) &= \int_{\omega^W} q(\omega,t)d\omega + \int_{\omega^E} q(\omega,t)d\omega \\
&= Q^W(t) + Q^E(t), \qquad \text{(B.3)}
\end{aligned}$$

which, dividing by $Q(t)$, writes as $1 = q^W(t) + q^E(t)$.

The quality aggregate in the West changes due to quality upgrades of Western products, the leadership takeover from the Eastern incumbent innovators and due to eastern direct innovation and leapfrogging over the West. The following expression describes the evolution of Q^W,

$$
\begin{aligned}
\dot{Q}^W(t) &= \int_{\omega^W}[\lambda^{(\sigma-1)(j(\omega,t)+1)} - \lambda^{(\sigma-1)j(\omega,t)}]I^W d\omega + \int_{\omega^E}\lambda^{(\sigma-1)(j(\omega,t)+1)}I^W d\omega \\
&- \int_{\omega^W}\lambda^{(\sigma-1)j(\omega,t)}I^E d\omega, \\
&= (\lambda^{\sigma-1}-1)I^W Q^W(t) + \lambda^{\sigma-1}I^W Q^E(t) - I^E Q^W(t).
\end{aligned} \tag{B.4}
$$

Similarly, for the aggregate quality of the eastern innovators,

$$
\begin{aligned}
\dot{Q}^E(t) &= \int_{\omega^E}[\lambda^{(\sigma-1)(j(\omega,t)+1)} - \lambda^{(\sigma-1)j(\omega,t)}]I^E d\omega + \int_{\omega^W}\lambda^{(\sigma-1)(j(\omega,t)+1)}I^E d\omega \\
&- \int_{\omega^E}\lambda^{(\sigma-1)j(\omega,t)}I^W d\omega \\
&= (\lambda^{\sigma-1}-1)I^E Q^E(t) + \lambda^{\sigma-1}I^E Q^W(t) - I^W Q^E(t),
\end{aligned} \tag{B.5}
$$

Finally, adding (B.4) and (B.5), and dividing by $Q(t)$ we obtain the equilibrium growth of the quality aggregate $Q(t)$ and its components which determines the growth rate of the the two regions given by equation (15).

B.1.2 Balanced growth path

Quality aggregates on the BGP Invariance of sectoral composition in any steady-state equilibrium requires that the growth rates of the average quality Q and its components (quality aggregates) must be constant and equal to each other.

Equating the growth of quality aggregates in the West and in the East, $\frac{\dot{Q}^W(t)}{Q^W(t)} = \frac{\dot{Q}^E(t)}{Q^E(t)}$, we obtain

$$
\frac{I^W}{I^E} = \frac{Q^W(t)}{Q^E(t)} \tag{B.6}
$$

which then gives equations

$$
\begin{aligned}
q^W &= \frac{I^W}{I^W + I^E} \\
q^E &= \frac{I^E}{I^W + I^E}.
\end{aligned} \tag{B.7}
$$

Sectoral composition. In steady state the shares of the two types of sectors in the economy, those with western leaders and production in the West and those with eastern leadership and production in the East, must be constant. Hence, the outflows and the inflows into each type of sectors have to be equalised. Formally, in the West $\omega^W(I^E) = \omega^E I^W$, where the right hand side is the flow out of sectors with western leadership and the left hand side is the flow into those sectors. The condition for the East is symmetric. Rearranging and using $\omega^W + \omega^E = 1$ we obtain the share of western and eastern sectors as functions of the innovation rates in the two regions, respectively,

$$\omega^W = \frac{I^W}{I^W + I^E}$$
$$\omega^E = \frac{I^E}{I^W + I^E}. \tag{B.8}$$

The sectoral shares of the two regions are identical to the above expressions for relative qualities in the West and the East, q^W and q^E.

We analyze a balanced growth path (BGP) with constant c^K and w^E. Equations (11) for the West and the East, (B.7), (15) and (B.1)-(B.2) define a set of BGP conditions for endogenous variables c^W, c^E, I^W, I^E, w^E, q^W and q^E. To close the model, we derive the expressions for the BGP per capita assets and expenditures below.

Assets. Assets per capita in each region given by (13) are derived as per capita value of all incumbent firms holding the existing patents. With constant wages and innovation arrival rates, and taking into account that $q(\omega,t)$ is fixed during an R&D race, it follows from the free entry condition (9) that the BGP growth in the firm value is found as $\dot{v^K}(t)/v^K(t) = -\dot{A}^K(t)/A^K(t) = -\phi g$, for $K = W,E$, with g as the growth rate of the average quality $Q(t)$ and each of its components, and thus also of the composite spillover $\hat{Q}^K(t)$.

Denoting the time of a patent's introduction in the market by a (with $t-a$ being the age of the patent at time t), and using the free entry condition (9) to express the value of the firms in terms of the innovation cost, we can derive the BGP per capita assets of the two regions as

$$\begin{aligned} \mathscr{A}^W(t) &= \int\limits_{\omega^W} \frac{v^W(\omega,t)}{L^W(t)} d\omega = \int\limits_{\omega^W} \frac{v^W(\omega,a)e^{-\phi g(t-a)}}{L^W(t)} d\omega = \int\limits_{\omega^W} (1-s^W) \frac{I^{W\frac{\alpha}{1-\alpha}}}{\gamma^W L^W(t)} \frac{q(\omega,a)}{\hat{Q}^W(a)^\phi} e^{-\phi g(t-a)} d\omega \\ &= (1-s^W) \frac{I^{W\frac{\alpha}{1-\alpha}}}{\gamma^W L^W(t)} \frac{\int_{\omega^W} q(\omega,a)}{(\hat{Q}^W(t)e^{-g(t-a)})^\phi} e^{-\phi g(t-a)} d\omega = (1-s^W) I^{W\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^W} \frac{Q^W(t)}{\hat{Q}^W(t)^\phi L^W(t)}, \end{aligned} \tag{B.9}$$

in the West, and similarly for the East

$$\begin{aligned} \mathscr{A}^E(t) &= \int\limits_{\omega^E} \frac{v^E(\omega,t)}{L^E(t)} d\omega = \int\limits_{\omega^E} \frac{v^E(\omega,a)e^{-\phi g(t-a)}}{L^E(t)} d\omega = \int\limits_{\omega^E} (1-s^E) \frac{I^{E\frac{\alpha}{1-\alpha}}}{\gamma^E L^E(t)} \frac{q(\omega,a)}{\hat{Q}^E(a)^\phi} e^{-\phi g(t-a)} d\omega \\ &= (1-s^E) \frac{I^{E\frac{\alpha}{1-\alpha}}}{\gamma^E L^E(t)} \frac{\int_{\omega^E} q(\omega,a)}{(\hat{Q}^E(t)e^{-g(t-a)})^\phi} e^{-\phi g(t-a)} d\omega = (1-s^E) I^{E\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^E} \frac{Q^E(t)}{\hat{Q}^E(t)^\phi L^E(t)}. \end{aligned} \tag{B.10}$$

Expenditures. Noting from the assets expressions above that assets per capita remain constant on the BGP when $g = \frac{n}{1-\phi}$, it follows that (12) can be written as $c^K(t) = w^K(t) + (\rho - n)\mathscr{A}^K - T^K(t)$. Substituting the two assets conditions above and the expressions for taxes per capita ($T^W(t) = \frac{s^W}{L^W(t)} \int_0^1 L_R^W(\omega,t) d\omega = s^W I^{W\frac{1}{1-\alpha}} \frac{1}{\gamma^W} \frac{Q(t)}{\hat{Q}^W(t)^\phi L^W(t)}$ and $T^E(t) = \frac{s^E}{L^E(t)} \int_0^1 L_R^E(\omega,t) d\omega = s^E w^E I^{E\frac{1}{1-\alpha}} \frac{1}{\gamma^E} \frac{Q(t)}{\hat{Q}^E(t)^\phi L^E(t)}$

for the West and the East, respectively) in the expressions for BGP per-capita consumer expenditure, we obtain the steady-state per capita consumption as

$$c^W = 1 + (\rho - n)\left[(1 - s^W) I^{W\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^W} \frac{Q^W(t)}{\hat{Q}^W(t)^\phi L^W(t)}\right] - s^W I^{W\frac{1}{1-\alpha}} \frac{1}{\gamma^W} \frac{Q(t)}{\hat{Q}^W(t)^\phi L^W(t)}, \tag{B.11}$$

for the West. Similarly, for the East

$$c^E \;=\; w^E\left(1 + (\rho - n)\left[(1 - s^E) w^E I^{E\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^E} \frac{Q^E}{\hat{Q}^E(t)^\phi L^E(t)}\right] - s^E I^{E\frac{1}{1-\alpha}} \frac{1}{\gamma^E} \frac{Q(t)}{\hat{Q}^E(t)^\phi L^E(t)}\right). \tag{B.12}$$

B.2 External effects in simplified model

Closed economy economy. We derive the equilibrium innovation rate for the simple closed economy version. We use a simple linear R&D technology, assuming $\alpha = 0$ and $A(\omega, t) = A$ constant. This is the same specification used in Impullitti (2010). Steady state equilibrium consumption and innovation are given by the expenditure equation and by the free entry condition:

$$c = 1 + c\frac{\lambda - 1}{\lambda} - \frac{I}{A}$$

$$\frac{c\frac{\lambda-1}{\lambda}}{I + \rho - n} A = 1.$$

Solving the system we obtain equilibrium I and c.

Open economy. Following the same procedure as in the closed economy simple model we derive the business stealing effect. The impact of the external innovation on Western consumption is

$$\frac{dc^W}{d\Phi} = \left(\frac{dc^W}{d\Phi} + \frac{dc^E}{d\Phi}\right)\frac{\lambda - 1}{\lambda}\hat{\omega}$$

where

$$\frac{dc^E}{d\Phi} = \left(\frac{dc^W}{d\Phi} + \frac{dc^E}{d\Phi}\right)\frac{\lambda - 1}{\lambda}(1 - \hat{\omega}) - (c^W + c^E)\frac{\lambda - 1}{\lambda}\frac{d\hat{\omega}}{d\Phi}.$$

Since the successful external innovation steals the profits of an Eastern firm but these profits are not given to a Western firm we have included the impact on profits only for the latter, which embeds the term $d\hat{\omega}/d\Phi$, the change in the leadership share produced by the external innovation. Along the balanced growth path $\hat{\omega} = I^W/(I^W + I^E)$. Since the innovation by the external agent does not feature here, in order to compute its impact on $\hat{\omega}$ we take $d\hat{\omega}/d\Phi = d\hat{\omega}/dI^W = 1 - \hat{\omega}$. Summing the above equations and multiplying by the probability that no other innovation occurs between s and t we get

$$\frac{dc^W}{d\Phi} = -(c^W + c^E)\frac{(\lambda-1)^2}{\lambda}\hat{\omega}(1-\hat{\omega})e^{-(I^W+I^E)(s-t)}.$$

Using this into the business stealing component of the change in utility

$$BSE^W_{open} = \int_t^\infty e^{-(\rho-n)(s-t)}\frac{1}{c^W}\frac{dc^W}{d\Phi}dt = \left(\frac{\lambda-1}{I^W+I^E+\rho-n}\right)\frac{\lambda-1}{\lambda}\hat{\omega}(1-\hat{\omega})\left(1+\frac{c^E}{c^W}\right)$$

Under the symmetric countries assumption we have $I^W + I^E = 2I$, $c^W = c^E$ and $\bar{\omega} = 1/2$, we obtain (22).

B.3 FDI and multinationals: full model details

B.3.1 Equilibrium conditions

Labor market clearing. Labor demand in the West comes from production located in the West, ω^W, and R&D activities in all sectors. Workers in the East are employed in production activities by western multinationals in ω^M sectors and by eastern firms in sectors ω^E. Labor demand for eastern workers comes also from western firms' adaptive R&D, targeting ω^W sectors for production transfer and from eastern firms' innovation in sectors where FDI has previously occurred (ω^M and ω^E). The labor market conditions are then derived as

$$\ell^W = \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} a^{W(1-\sigma)}q^W\left(\frac{c^W\ell^W}{\bar{P}^{W(1-\sigma)}} + \frac{c^E(1-\ell^W)}{\bar{P}^{E(1-\sigma)}}\tau^{W(1-\sigma)}\right) + \frac{I^{W\frac{1}{1-\alpha}}}{\gamma^W}\frac{Q(t)}{\hat{Q}^W(t)^\phi L(t)} \quad \text{(B.13)}$$

in the West, and in the East,

$$\begin{aligned} 1-\ell^W &= \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} w^{E(-\sigma)}\left[a^{M(1-\sigma)}q^M\left(\frac{c^W\ell^W}{\bar{P}^{W(1-\sigma)}}\tau^{E(1-\sigma)} + \frac{c^E(1-\ell^W)}{\bar{P}^{E(1-\sigma)}}\right)\right. \\ &+ \left. a^{E(1-\sigma)}q^E\left(\frac{c^W\ell^W}{\bar{P}^{W(1-\sigma)}}\tau^{E(1-\sigma)} + \frac{c^E(1-\ell^W)}{\bar{P}^{E(1-\sigma)}}\right)\right] \\ &+ \frac{I^{M\frac{1}{1-\alpha}}}{\gamma^M}\frac{Q^W(t)}{\hat{Q}^W(t)^\phi L(t)} + \frac{I^{E\frac{1}{1-\alpha}}}{\gamma^E}\frac{Q^{(M+E)}(t)}{\hat{Q}^E(t)^\phi L(t)}. \end{aligned} \quad \text{(B.14)}$$

Quality aggregates. The average quality index $Q(t)$ equals the sum of the sectoral quality aggretates

$$\begin{aligned} Q(t) &= \int_{\omega^W} q(\omega,t)d\omega + \int_{\omega^E} q(\omega,t)d\omega + \int_{\omega^M} q(\omega,t)d\omega \\ &= Q^W(t) + Q^E(t) + Q^M(t), \end{aligned} \tag{B.15}$$

which gives the condition $1 = q^W(t) + q^E(t) + q^M(t)$. The quality aggregate in the West changes due to quality upgrades of Western products, leadership takeover from the Eastern incumbent innovators and the multinationals and due to the transfer of production to subsidiary firms in the East. The following expression describes the evolution of Q^W, as a result of innovation and production transfers

$$\begin{aligned} \dot{Q}^W(t) &= \int_{\omega^W} [\lambda^{(\sigma-1)(j(\omega,t)+1)} - \lambda^{(\sigma-1)j(\omega,t)}] I^W d\omega + \int_{\omega^E} \lambda^{(\sigma-1)(j(\omega,t)+1)} I^W d\omega \\ &+ \int_{\omega^M} \lambda^{(\sigma-1)(j(\omega,t)+1)} I^W d\omega - \int_{\omega^W} \lambda^{(\sigma-1)j(\omega,t)} I^M d\omega, \\ &= (\lambda^{\sigma-1} - 1) I^W Q^W(t) + \lambda^{\sigma-1} I^W (Q^E(t) + Q^M(t)) - I^M Q^W(t). \end{aligned} \tag{B.16}$$

Similarly, for the aggregate quality of the eastern innovators and multinationals' production

$$\begin{aligned} \dot{Q}^E(t) &= \int_{\omega^E} [\lambda^{(\sigma-1)(j(\omega,t)+1)} - \lambda^{(\sigma-1)j(\omega,t)}] I^E d\omega + \int_{\omega^M} \lambda^{(\sigma-1)(j(\omega,t)+1)} I^E d\omega - \int_{\omega^E} \lambda^{(\sigma-1)j(\omega,t)} I^W d\omega \\ &= (\lambda^{\sigma-1} - 1) I^E Q^E(t) + \lambda^{\sigma-1} I^E Q^M(t) - I^W Q^E(t), \end{aligned} \tag{B.17}$$

$$\begin{aligned} \dot{Q}^M(t) &= \int_{\omega^W} \lambda^{(\sigma-1)j(\omega,t)} I^M d\omega - \int_{\omega^M} \lambda^{(\sigma-1)j(\omega,t)} I^W d\omega - \int_{\omega^M} \lambda^{(\sigma-1)j(\omega,t)} I^E d\omega \\ &= I^M Q^W(t) - (I^W + I^E) Q^M(t) \end{aligned} \tag{B.18}$$

The average product quality of all the production in the East is given by $Q^{EM}(t) = Q^E(t) + Q^M(t)$ and it evolves according to

$$\begin{aligned} \dot{Q}^{EM}(t) &= \dot{Q}^E(t) + \dot{Q}^M(t) \\ &= (\lambda^{\sigma-1} - 1) I^E Q^{EM} + I^M Q^W(t) - I^W (Q^E(t) + Q^M(t)). \end{aligned}$$

Finally, adding (B.16), (B.17), (B.18) and dividing by $Q(t)$ we obtain equation (26).

B.3.2 Balanced growth path

Balanced growth free entry conditions. As noted in the benchmark model description for the BGP, with constant wages and innovation arrival rates, $\dot{v}^k(t)/v^k(t) = -\dot{A}^k(t)/A^k(t) = -\phi g$, for $k = W, E, M$. Substituting for profits and the marginal product of research (MRI) in (25), we determine the BGP free entry conditions in three different types of sectors (firms) as

$$\frac{(1-s^W)}{\gamma^W} \frac{Q(t)}{\hat{Q}^W(t)^\phi L(t)} = \frac{\frac{a^{W(1-\sigma)}\sigma^{-\sigma}}{(\sigma-1)^{(1-\sigma)}} \left(\frac{c^W \ell^W(t)}{(\bar{P}^W(t))^{(1-\sigma)}} + \frac{c^E(1-\ell^W(t))}{(\bar{P}^E(t))^{(1-\sigma)}} \tau^{W(1-\sigma)} \right)}{\rho + I^W + \phi g} I^{W\frac{\alpha}{\alpha-1}} \quad \text{for } \omega \in \omega^W, \tag{B.19}$$

$$\frac{(1-s^E)w^E}{\gamma^E}\frac{Q(t)}{\hat{Q}^E(t)^\phi L(t)} = \frac{\frac{\sigma^{-\sigma}}{(\sigma-1)^{(1-\sigma)}} a^{E(1-\sigma)} w^{E(1-\sigma)} \left(\frac{c^W \ell^W(t)}{(\bar{P}^W(t))^{(1-\sigma)}}\tau^{E(1-\sigma)} + \frac{c^E(1-\ell^W(t))}{(\bar{P}^E(t))^{(1-\sigma)}}\right)}{\rho + I^W + I^E + \phi g} I^{E\frac{\alpha}{\alpha-1}} \quad \text{for } \omega \in \omega^E, \tag{B.20}$$

$$\frac{(1-s^M)w^E}{\gamma^M}\frac{Q(t)}{\hat{Q}^W(t)^\phi L(t)} = \frac{\sigma^{-\sigma}}{(\sigma-1)^{(1-\sigma)}}\left[\frac{a^{M(1-\sigma)}w^{E(1-\sigma)}}{\rho + I^W + I^E + \phi g}\left(\frac{c^W \ell^W(t)}{(\bar{P}^W(t))^{(1-\sigma)}}\tau^{E(1-\sigma)} + \frac{c^E(1-\ell^W(t))}{(\bar{P}^E(t))^{(1-\sigma)}}\right)\right.$$
$$\left. - \frac{a^{W(1-\sigma)}}{\rho + I^W + \phi g}\left(\frac{c^W \ell^W(t)}{(\bar{P}^W(t))^{(1-\sigma)}} + \frac{c^E(1-\ell^W(t))}{(\bar{P}^E(t))^{(1-\sigma)}}\tau^{W(1-\sigma)}\right)\right] I^{M\frac{\alpha}{\alpha-1}} \quad \text{for } \omega \in \omega^M. \tag{B.21}$$

Quality aggregates on the BGP. Equating the growth of quality aggregates in the West and in the East, $\frac{\dot{Q}^W(t)}{Q^W(t)} = \frac{\dot{Q}^{EM}(t)}{Q^{EM}(t)}$, to satisfy the invariance of sectoral composition, we obtain

$$\lambda^{\sigma-1}\frac{I^W}{q^W} = \frac{I^M}{q^M + q^E} + (\lambda^{\sigma-1} - 1)\frac{I^E(q^M + q^E)}{q^M + q^E}. \tag{B.22}$$

Similarly, the growth rate of quality aggregates of the eastern innovating firms in sectors with previous FDI and the multinational firms has to be the same in a steady-state equilibrium, $\frac{\dot{Q}^E(t)}{Q^E(t)} = \frac{\dot{Q}^M(t)}{Q^M(t)}$, which yields the condition

$$\frac{q^W(t)}{q^M(t) + q^E(t)} = \lambda^{\sigma-1}\frac{I^E}{I^M}\frac{q^M(t)}{q^E(t)}. \tag{B.23}$$

Sectoral composition. In steady state the shares of the three types of sectors in the economy must be constant. In the West, $\omega^W(I^M) = (\omega^M + \omega^E)I^W$, where the right hand side is the flow out of sectors with western leadership and the left hand side is the flow into those sectors. Rearranging we obtain $\omega^W = \frac{I^W}{I^M + I^W}$. The condition for the sectors with eastern leadership is given by $\omega^E I^W = \omega^M I^E$, which, using $\omega^W + \omega^M + \omega^E = 1$, yields $\omega^E = \frac{I^M}{I^M + I^W}\frac{I^E}{I^E + I^W}$. Finally, the share of sectors with production by multinationals is given by $\omega^M = \frac{I^M}{I^M + I^W}\frac{I^W}{I^E + I^W}$.

Equations (25) for the three types of sectors, (B.22)-(B.23), (26) and (B.13)-(B.14) define a set of BGP conditions for endogenous variables c^W, c^E, I^W, I^E, I^M, w^E, q^W, q^M and q^E. We derive the expressions for per capita assets and expenditures below.

Assets and expenditures. We assume that western households finance both the innovative and adaptive R&D in the West and the East and thus receive, in the form of dividends, the profits of firms operating in the West and the profits of multinational firms (sum of profits previously being obtained through production in the West and the increase in profits due to production transfer to the low-cost

East). The total stock of per capita assets is then given by

$$\begin{aligned}\mathscr{A}^W &= \int\limits_{\omega^W+\omega^M} \frac{v^W(\omega,t)}{L^W(t)}d\omega + \int\limits_{\omega^M} \frac{v^M(\omega,t)-v^W(\omega,t)}{L^W(t)}d\omega \\ &= (1-s^W)\frac{I^{W\frac{\alpha}{1-\alpha}}}{\gamma^W}\frac{Q^{(W+M)}(t)}{\hat{Q}^W(t)^\phi L^W(t)} + (1-s^M)w^E\frac{I^{M\frac{\alpha}{1-\alpha}}}{\gamma^M}\frac{Q^M(t)}{\hat{Q}^W(t)^\phi L^W(t)}. \end{aligned} \tag{B.24}$$

The total assets value in the East comes from eastern firms' market leadership through innovation through the E sectors. Then, the total stock of per capita assets is derived as

$$\begin{aligned}\mathscr{A}^E &= \int\limits_{\omega^E} \frac{v^E(\omega,t)}{L^E}d\omega \\ &= (1-s^E)w^E\frac{I^{E\frac{\alpha}{1-\alpha}}}{\gamma^E}\frac{Q^E(t)}{\hat{Q}^E(t)^\phi L^E(t)}. \end{aligned} \tag{B.25}$$

Substituting the two conditions above in the expressions for per-capita consumer expenditure (12) we obtain the steady-state per capita expenditure in the West as

$$\begin{aligned}c^W &= 1+(\rho-n)\left[(1-s^W)\frac{Q^{(W+M)}}{\gamma^W\hat{Q}^W(t)^\phi}\frac{I^{W\frac{\alpha}{1-\alpha}}}{L^W(t)} + (1-s^M)w^E\frac{Q^M}{\gamma^M\hat{Q}^W(t)^\phi}\frac{I^{M\frac{\alpha}{1-\alpha}}}{L^W(t)}\right] \\ &- s^W I^{W\frac{1}{1-\alpha}}\frac{Q(t)}{\gamma^W\hat{Q}^W(t)^\phi L^W(t)}. \end{aligned} \tag{B.26}$$

The last term represents per capita lump-sum tax, where total taxes equal total subsidies, i.e. $T^W(t)L^W(t) = s^W I^{W\frac{1}{1-\alpha}}\frac{Q(t)}{\gamma^W\hat{Q}^W(t)^\phi}$. Similarly for the East,

$$\begin{aligned}c^E &= w^E\Bigg(1+(\rho-n)\left[(1-s^E)\frac{Q^E(t)}{\gamma^E\hat{Q}^E(t)^\phi}\frac{I^{E\frac{\alpha}{1-\alpha}}}{L^E(t)}\right] \\ &- s^E I^{E\frac{1}{1-\alpha}}\frac{Q^{(M+E)}(t)}{\gamma^E\hat{Q}^E(t)^\phi L^E(t)} - s^M I^{M\frac{1}{1-\alpha}}\frac{Q^W(t)}{\gamma^M\hat{Q}^W(t)^\phi L^E(t)}\Bigg), \end{aligned} \tag{B.27}$$

with the last two terms in parenthesis capturing the subsidised part of the innovation and adaptation cost in the East, financed by the eastern lump-sum tax.

B.4 Fully endogenous model

Modeling fully endogenous growth requires a change in our specification of the innovation technology as described in the main text, but the rest of the model is unchanged and so are the equilibrium quality aggregates and sectoral composition conditions derived above. The change in the R&D technology (7) and the R&D productivity (8) affects the free entry condition (9), and thus the labor market clearing and the assets and expenditure conditions. We define the latter conditions in this section, as well as the respective ones in the following section on fully endogenous model with FDI.

Labor market clearing. We derive the labor market clearing condition in the West as

$$\begin{aligned}\ell^W &= \int_{\omega^W} a^W q(\omega,t) p^{W(-\sigma)} \frac{c^W \ell^W}{P^W(t)^{1-\sigma}} d\omega + \int_{\omega^W} \tau^W a^W q(\omega,t) p^{*W(-\sigma)} \frac{c^E(1-\ell^W)}{P^E(t)^{1-\sigma}} d\omega + \int_0^1 \frac{I^{W\frac{1}{1-\alpha}} X(t)}{A^W(t)L(t)} d\omega \\ &= (\frac{\sigma}{\sigma-1})^{-\sigma} a^{W(1-\sigma)} q^W \left(\frac{c^W \ell^W}{\bar{P}^W(t)^{1-\sigma}} + \frac{c^E(1-\ell^W)}{\bar{P}^E(t)^{1-\sigma}} \tau^{W(1-\sigma)} \right) + \frac{I^{W\frac{1}{1-\alpha}}}{\gamma^W} \frac{2\kappa Q(t)}{\hat{Q}^W(t)}, \end{aligned} \tag{B.28}$$

and in the East we obtain,

$$\begin{aligned}1-\ell^W &= \int_{\omega^E} \tau^E a^E q(\omega,t) p^{*E(-\sigma)} \frac{c^W l^W}{P^W(t)^{1-\sigma}} d\omega + \int_{\omega^E} a^E q(\omega,t) p^{E(-\sigma)} \frac{c^E(1-\ell^W)}{P^E(t)^{1-\sigma}} d\omega + \int_0^1 \frac{I^{E\frac{1}{1-\alpha}} X(t)}{A^E(t)L(t)} d\omega \\ &= \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} w^{E(-\sigma)} a^{E(1-\sigma)} q^E \left(\frac{c^W l^W}{\bar{P}^{W(1-\sigma)}} \tau^{E(1-\sigma)} + \frac{c^E(1-l^W)}{\bar{P}^{E(1-\sigma)}} \right) + \frac{I^{E\frac{1}{1-\alpha}}}{\gamma^E} \frac{2\kappa Q(t)}{\hat{Q}^E(t)}. \end{aligned} \tag{B.29}$$

Assets. We can derive the per capita assets of the two regions as

$$\mathscr{A}^W = \int_{\omega^W} \frac{v^W(\omega,t)}{L^W(t)} d\omega = \int_{\omega^W} (1-s^W) \frac{I^{W\frac{\alpha}{1-\alpha}} X(t)}{\gamma^W L^W(t)} \frac{q(\omega,t)}{\hat{Q}^W(t)} d\omega = (1-s^W) I^{W\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^W} \frac{2\kappa Q^W(t)}{\hat{Q}^W(t)\ell^W}, \tag{B.30}$$

in the West, and similarly for the East

$$\mathscr{A}^E = \int_{\omega^E} \frac{v^E(\omega,t)}{L^E(t)} d\omega = \int_{\omega^E} (1-s^E) w^E \frac{I^{E\frac{\alpha}{1-\alpha}} X(t)}{\gamma^E L^E(t))} \frac{q(\omega,t)}{\hat{Q}^E(t)} d\omega = (1-s^E) w^E I^{E\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^E} \frac{2\kappa Q^E}{\hat{Q}^E(t)(1-\ell^W)} \tag{B.31}$$

Expenditures. Using the two assets conditions above and the expressions for taxes per capita ($T^W(t) = s^W I^{W\frac{1}{1-\alpha}} \frac{1}{\gamma^W} \frac{2\kappa Q(t)}{\hat{Q}^W(t)\ell^W}$ and $T^E(t) = s^E w^E I^{E\frac{1}{1-\alpha}} \frac{1}{\gamma^E} \frac{2\kappa Q(t)}{\hat{Q}^E(t)(1-\ell^W)}$ for the West and the East, respectively), we obtain the steady-state per capita expenditures as

$$c^W = 1 + (\rho - n)\left[(1-s^W) I^{W\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^W} \frac{2\kappa Q^W(t)}{\hat{Q}^W(t)\ell^W}\right] - s^W I^{W\frac{1}{1-\alpha}} \frac{1}{\gamma^W} \frac{2\kappa Q(t)}{\hat{Q}^W(t)\ell^W}, \tag{B.32}$$

$$c^E = w^E \left(1 + (\rho - n)\left[(1-s^E) w^E I^{E\frac{\alpha}{1-\alpha}} \frac{1}{\gamma^E} \frac{2\kappa Q^E}{\hat{Q}^E(t)(1-\ell^W)}\right] - s^E I^{E\frac{1}{1-\alpha}} \frac{1}{\gamma^E} \frac{2\kappa Q(t)}{\hat{Q}^E(t)(1-\ell^W)}\right). \tag{B.33}$$

C Computational Appendix

The following gives the algorithm for finding the transition path after a policy change.

1. Designate the finite differences time interval length $\Delta > 0$. Increments of this object will be indexed by δ. Conjecture the number of intervals until the new steady state is reached after a reform $T \in \mathbb{N}$.

2. Solve for the pre- and post-reform steady states of the model. Solving for a steady state gives a list of endogeneous objects

$$\vec{\Gamma} = (I^W, I^E, w^E, x^W, x^E, q^W, q^E, \mathscr{A}^W, \mathscr{A}^E, c^W, c^E)$$

where $x^W = \frac{\hat{Q}^W(t)^\phi L(t)}{Q(t)}$ and $x^E = \frac{\hat{Q}^E(t)^\phi L(t)}{Q(t)}$. Denote the sets of objects found in the pre and post-reform steady states by $\vec{\Gamma}_0$ and $\vec{\Gamma}_{T\Delta}$ respectively.

3. Conjecture the set of objects

$$\vec{\Psi} = \{I^W_\delta, I^E_\delta, w^E_\delta, r^W_\delta, r^E_\delta\}_{\delta=\Delta}^{T\Delta} \tag{C.1}$$

for $\delta = \Delta, 2\Delta, 3\Delta, ..., T\Delta$ where r^K_δ is the riskless rate in country $K \in \{W, E\}$.

4. Given conjecture C.1, iterate forwards on the laws of motion for the quality shares (B.4) and (B.5). This yields the sequence $\vec{Q} = \{q^W_\delta, q^E_\delta\}_{\delta=\Delta}^{T\Delta}$ as well as $\vec{G} = \{g^W_\delta, g^E_\delta, g_\delta\}_{\delta=\Delta}^{T\Delta}$ where the latter objects are the growth rates in the quality of Western-led, Eastern-led and all industries respectively.

5. Use the definitions of x^W and x^E alongside $\vec{Q}$ and $\vec{G}$ to obtain sequence $\vec{X} = \{x^W_\delta, x^E_\delta\}_{\delta=\Delta}^{T\Delta}$.

6. Find the sequence $\vec{T} = \{T^W_\delta, T^E_\delta\}_{\delta=\Delta}^{T\Delta}$ of tax payments from the household using $\vec{\Psi}$, $\vec{Q}$ and $\vec{X}$.

7. Solve the household problem in each country $K \in \{W, E\}$ to obtain objects $\vec{A}^D = \{\mathscr{A}^W_\delta, \mathscr{A}^E_\delta\}_{\delta=\Delta}^{T\Delta}$ (asset demand) and $\vec{C} = \{c^W_\delta, c^E_\delta\}_{\delta=\Delta}^{T\Delta}$ (nominal expenditure) as follows.

   (a) Conjecture an impact level of nominal expenditure on goods c^K_Δ.

   (b) Find the level of asset holdings from the household budget constraint (12) with $\vec{T}$ using c^K_δ and $\mathscr{A}^K_{\delta-\Delta}$. The initial condition for assets in the case of $\delta = \Delta$ is $\mathscr{A}^K$ from $\vec{\Gamma}_0$.

   (c) Find the implied value of expenditure next time increment using the Euler equation (3).

   (d) Continue with steps (b) and (c) until reaching time $T\Delta$.

   (e) Check the distance from the terminal steady state asset level found in $\vec{\Gamma}_{T\Delta}$.

   (f) Update the initial guess c^K_Δ, return to step (b) and continue until convergence.

8. Find the sequences $\vec{P} = \{\bar{P}^W_\delta, \bar{P}^E_\delta\}_{\delta=\Delta}^{T\Delta}$ using the definitions of the de-trended CPI, $\vec{Q}$ and $\vec{\Psi}$.

9. Find the sequence of growth rates in profits $\vec{\Pi} = \{g^W_{\pi,\delta}, g^E_{\pi,\delta}\}_{\delta=\Delta}^{T\Delta}$ where $g^K_{\pi,\delta} = \pi^K(\delta)/\pi^K(\delta - \Delta)$ for $K \in \{W, E\}$ using (6), $\vec{C}$, $\vec{P}$ and $\vec{\Psi}$.

10. Find the growth in the incumbent value function $\vec{V} = \{g^W_{v,\delta}, g^E_{v,\delta}\}_{\delta=\Delta}^{T\Delta}$ where $g^K_{v,\delta} = v^K(\delta)/v^K(\delta - \Delta)$ by iterating backwards from time $T\Delta$ using $\vec{\Pi}$, $\vec{\Psi}$ and expression (10).

11. Find the supply of assets using $\vec{V}$, $\vec{C}$, $\vec{P}$, $\vec{Q}$ and $\vec{\Psi}$ with equation (10) and the expression

$$\widehat{\mathscr{A}^K_\delta}(t) = \int_{\omega^K} \frac{v^K(\omega, t)}{L^K(t)} d\omega$$

for $K \in \{W, E\}$ to obtain the sequence $\vec{A}^S = \{\widehat{\mathscr{A}^W_\delta}, \widehat{\mathscr{A}^E_\delta}\}_{\delta=\Delta}^{T\Delta}$.

12. Use $\vec{V}$, $\vec{\Psi}$, $\vec{P}$, $\vec{C}$, $\vec{A}^S$, $\vec{A}^D$ and $\vec{X}$ to compute the distance from free entry, labour market clearing and excess demand for assets in each market and instant in time $\delta = \Delta, 2\Delta, ..., T\Delta$. Then update the objects in $\vec{\Psi}$ accordingly and return to step 4. Repeat until all equilibrium conditions at every moment in time are sufficiently small. If the model has not converged by increment T, increase T and return to step 3.

D Additional figures

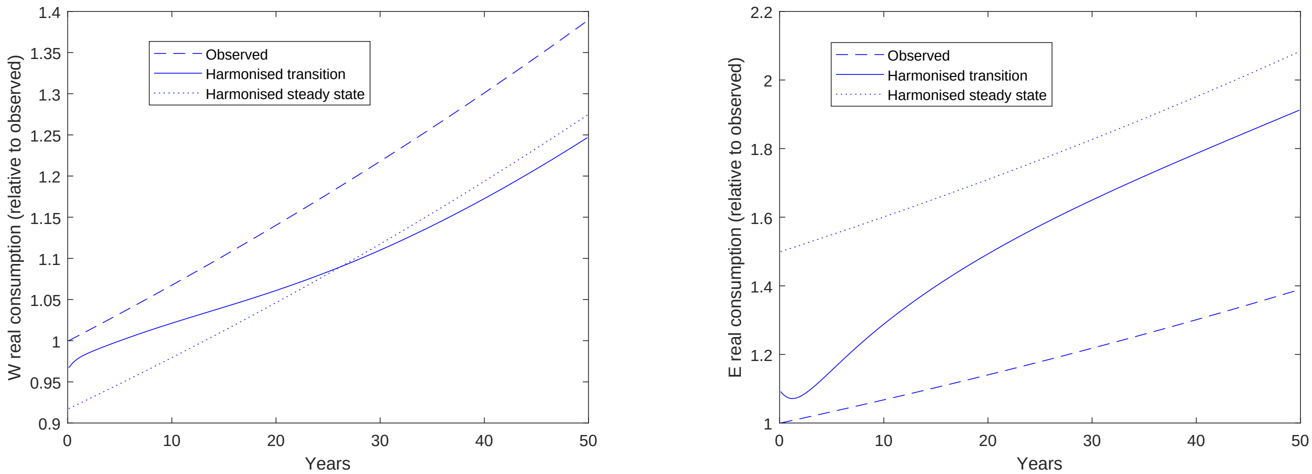
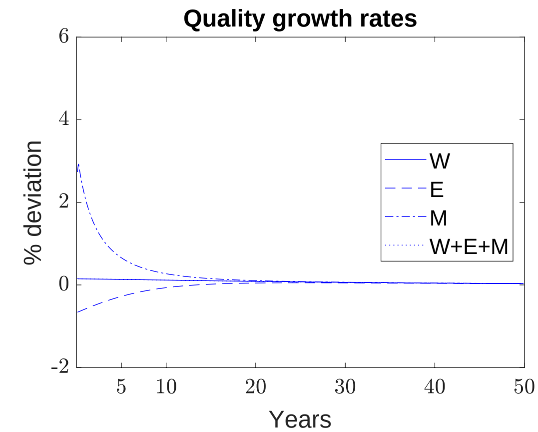
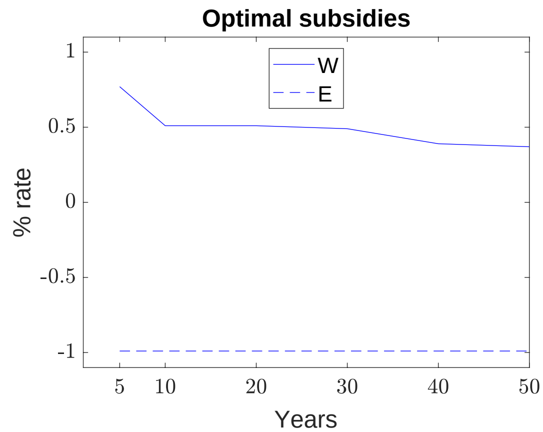


Figure D.1: Transitional dynamics: real consumption

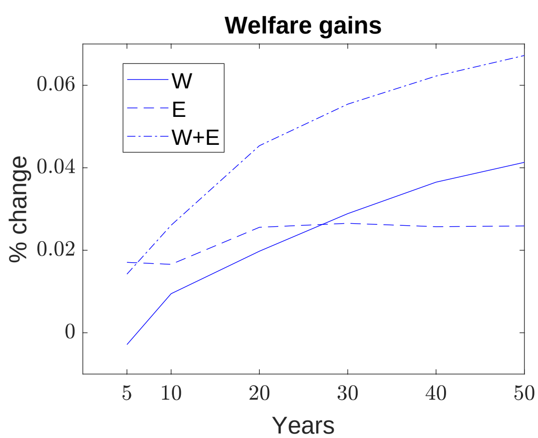
Notes: The figure shows the path of real consumption in the West (left) and East (right) under the observed subsidies, the harmonised subsidies in steady state and harmonised subsidies along the transition.



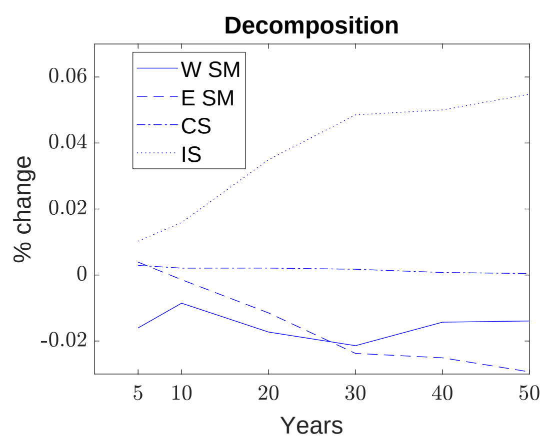
(a) Growth under cooperative subsidies



(b) Cooperative subsidies (policy horizons)



(c) Gains from cooperation (policy horizons)



(d) Gains decomposition (policy horizons)

Figure D.2: Growth dynamics and policy maker horizon

Notes: Panel a) shows the transitional dynamics of growth rate of Q, Q^W and Q^E under cooperative subsidies as deviation from the baseline. Panel b) reports the cooperative subsidies for different policy maker horizons. Panels c) and d) show the gains from cooperation and their decomposition for different policy horizons.

E Additional tables

Table E.1: Calibration summary (FDI extension)

External parameters	Value	Source
Interest rate ($r = \rho$)	0.04	Eurostat, 2001-2013
Population growth rate (n)	0.44%	Eurostat, 1961-2013
R&D subsidy, West (s^W)	12.2%	OECD, 2011
R&D subsidy, East (s^E)	9.70%	OECD, 2011
Relative labor size, West (l^W)	0.80	Eurostat, 2015
Calibrated parameters	Value	
Utility f-n parameter (σ)	2.67	
Innovative R&D productivity parameter, West (γ^W)	0.50	
Innovative R&D productivity parameter, East (γ^E)	0.40	
Innovative R&D productivity parameter, MNE (γ^M)	0.25	
Manufacturing productivity, East (a^E)	1.20	
Manufacturing productivity, East (a^M)	1.60	
Spillover parameter (β)	0.60	
Quality jump size (λ)	2.20	
Decreasing returns (α)	0.52	
Spillover (ϕ)	0.60	

Table E.2: Calibration summary: fully endogenous

External parameters	Value	Source
Interest rate ($r = \rho$)	0.04	Eurostat, 2005-2016
Population growth rate (n)	0.44%	Eurostat, 2005-2016
Relative labor size, West (l^W)	0.80	Eurostat, 2005-2016
R&D subsidy, West (s^W)	12.2%	OECD, 2005-2016
R&D subsidy, East (s^E)	9.70%	OECD, 2005-2016
Difficulty index scaler (κ)	1.00	normalisation
Calibrated parameters	Value	
Utility f-n parameter (σ)	19.3	
Innovative R&D productivity parameter, West (γ^W)	5.00	
Innovative R&D productivity parameter, East (γ^E)	2.00	
Manufacturing productivity, East (a^E)	1.70	
Spillover parameter (β)	0.80	
Quality jump size (λ)	1.02	
Decreasing returns (α)	0.45	
Moments	Data (Model)	Source
East relative wage (w^E)	0.60 (0.58)	Eurostat, 2005-2016
MFP growth rate	0.66% (0.60%)	OECD 2005-2016
Share of sectors, West leadership (ω^W)	91% (91%)	OECD, 2005-2016
West R&D expenditure/GDP	3.87% (3.69%)	Eurostat, 2015
East R&D expenditure/GDP	2.12% (3.59%)	Eurostat, 2015
West share of labour in R&D	3.13% (3.71%)	Eurostat, 2015
East share of labour in R&D	2.22% (3.68%)	Eurostat, 2015
West innovation elasticity to subsidy	[0.7, 3.5] (1.29)	Akcigit et al. (2018)
East innovation elasticity to subsidy	[0.7, 3.5] (1.24)	Akcigit et al. (2018)

F Robustness

Table F.1: Intertemporal knowledge spillovers and policy cooperation

	$\underline{\phi} = 0.639$			$\phi_b = 0.6$			$\bar{\phi} = 0.781$		
	s^W	s^E		s^W	s^E		s^W	s^E	
Observed (s_o^W, s_o^E)	0.122	0.097		0.122	0.097		0.122	0.097	
Nash (s_n^W, s_n^E)	0.57	0.49		0.55	0.47		0.53	0.45	
Harmonised (s_{har})	-0.55	0.59		-0.39	0.59		-0.19	0.59	
Welfare gains	W	E	W+E	W	E	W+E	W	E	W+E
Harmonised vs Nash	-0.081	0.245	0.164	-0.08	0.25	0.17	-0.079	0.241	0.162
strategic motive	0.071	0.397	0.468	0.07	0.41	0.48	0.071	0.391	0.462
consumer surplus	-0.067	-0.067	-0.134	-0.07	-0.06	-0.12	-0.045	-0.045	-0.090
intertemporal spillovers	-0.086	-0.086	-0.172	-0.10	-0.10	-0.20	-0.106	-0.106	-0.212
Harmonised vs Observed	-0.077	0.228	0.151	-0.07	0.23	0.16	-0.056	0.227	0.171
strategic motive	0.020	0.325	0.345	0.02	0.32	0.34	0.014	0.297	0.311
consumer surplus	-0.069	-0.069	-0.138	-0.06	-0.06	-0.12	-0.049	-0.049	-0.098
intertemporal spillovers	-0.028	-0.028	-0.056	-0.03	-0.03	-0.06	-0.021	-0.021	-0.042

Notes. Sensitivity analysis performed for a 10% plus or minus deviation from the baseline value ϕ_p.

Table F.2: International knowledge spillovers and policy cooperation

	$\underline{\beta} = 0.54$			$\beta_b = 0.6$			$\bar{\beta} = 0.66$		
	s^W	s^E		s^W	s^E		s^W	s^E	
Observed (s_o^W, s_o^E)	0.122	0.097		0.122	0.097		0.122	0.097	
Nash (s_n^W, s_n^E)	0.57	0.43		0.55	0.47		0.53	0.47	
Harmonised (s_{har})	-0.31	0.59		-0.39	0.59		-0.51	0.59	
Welfare gains	W	E	W+E	W	E	W+E	W	E	W+E
Harmonised vs Nash	-0.079	0.254	0.175	-0.08	0.25	0.17	-0.087	0.279	0.192
strategic motive	0.078	0.410	0.488	0.07	0.41	0.48	0.074	0.440	0.514
consumer surplus	-0.059	-0.059	-0.118	-0.07	-0.06	-0.12	-0.060	-0.060	-0.012
intertemporal spillovers	-0.097	-0.097	-0.194	-0.10	-0.10	-0.20	-0.101	-0.101	-0.202
Harmonised vs Observed	-0.064	0.207	0.143	-0.07	0.23	0.16	-0.077	0.261	0.184
strategic motive	0.016	0.287	0.303	0.02	0.32	0.34	0.022	0.359	0.381
consumer surplus	-0.058	-0.058	-0.116	-0.06	-0.06	-0.12	-0.064	-0.064	-0.128
intertemporal spillovers	-0.022	-0.022	-0.044	-0.03	-0.03	-0.06	-0.034	-0.034	-0.068

Notes. Sensitivity analysis performed for a 10% plus or minus deviation from the baseline value β_p.

Table F.3: Local decreasing returns to R&D and policy cooperation

	$\underline{\alpha} = 0.18$			$\alpha_b = 0.2$			$\bar{\alpha} = 0.22$		
	s^W	s^E		s^W	s^E		s^W	s^E	
Observed (s_o^W, s_o^E)	0.122	0.097		0.122	0.097		0.122	0.097	
Nash (s_n^W, s_n^E)	0.57	0.43		0.55	0.47		0.55	0.47	
Harmonised (s_{har})	-0.49	0.59		-0.39	0.59		-0.41	0.61	
Welfare gains	W	E	W+E	W	E	W+E	W	E	W+E
Harmonised vs Nash	-0.082	0.248	0.166	-0.08	0.25	0.17	-0.093	0.259	0.166
strategic motive	0.071	0.401	0.472	0.07	0.41	0.48	0.076	0.428	0.504
consumer surplus	-0.054	-0.054	-0.108	-0.07	-0.06	-0.12	-0.072	-0.072	-0.144
intertemporal spillovers	-0.099	-0.099	-0.198	-0.10	-0.10	-0.20	-0.100	-0.100	-0.200
Harmonised vs Observed	-0.072	0.247	0.175	-0.07	0.23	0.16	-0.079	0.229	0.150
strategic motive	0.020	0.340	0.360	0.02	0.32	0.34	0.019	0.327	0.346
consumer surplus	-0.059	-0.059	-0.118	-0.06	-0.06	-0.12	-0.072	-0.072	-0.144
intertemporal spillovers	-0.033	-0.033	-0.066	-0.03	-0.03	-0.06	-0.026	-0.026	-0.052

Notes. Sensitivity analysis performed for a 10% plus or minus deviation from the baseline value α_p.

Table F.4: Trade costs and policy cooperation

	$\tau_b = 1$			$\tau = 1.1$			$\tau = 1.2$		
	s^W	s^E		s^W	s^E		s^W	s^E	
Observed (s_o^W, s_o^E)	0.122	0.097		0.122	0.097		0.122	0.097	
Nash (s_n^W, s_n^E)	0.55	0.47		0.55	0.47		0.47	0.51	
Harmonised (s_{har})	-0.39	0.59		-0.47	0.59		-0.47	0.61	
Welfare gains	W	E	W+E	W	E	W+E	W	E	W+E
Harmonised vs Nash	-0.08	0.25	0.17	-0.094	0.284	0.190	-0.098	0.245	0.147
strategic motive	0.07	0.41	0.48	0.077	0.440	0.515	0.060	0.371	0.431
consumer surplus	-0.07	-0.06	-0.12	-0.069	-0.051	-0.120	-0.074	-0.042	-0.116
intertemporal spillovers	-0.10	-0.10	-0.20	-0.102	-0.102	-0.205	-0.084	-0.084	-0.168
Harmonised vs Observed	-0.07	0.23	0.16	-0.081	0.253	0.173	-0.089	0.275	0.186
strategic motive	0.02	0.32	0.34	0.021	0.341	0.362	0.021	0.357	0.378
consumer surplus	-0.06	-0.06	-0.12	-0.070	-0.057	-0.127	-0.080	-0.05	-0.132
intertemporal spillovers	-0.03	-0.03	-0.06	-0.031	-0.031	-0.062	-0.030	-0.030	-0.060

Notes. Sensitivity analysis performed for a plus 10% and 20% deviation from the baseline value.