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Delivering public investment efficiently: If possible, avoid delays

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Abstract

Public investment can be used to affect the economy over the business cycle, but also to boost its long-term potential. However, public investment is often subject to delays related to planning, construction, or both. We show that these delays can materially affect the usefulness of public investment for managing the economy. In particular in the case of a downturn, a delay in delivering an announced public investment can worsen the downturn if public investment is not delivered quickly. If public investment that has been planned during the recession is delayed so that it occurs when the recession is over, it risks overheating the economy. Delays in the delivery of public investment shift the benefits from higher public capital further into the future and reduce welfare. These findings hold in the standard model as well as in the model with search frictions, but with search frictions planning delays become less concerning, because the business cycle induced by the delay becomes smoother.

JEL classification: E24, E32, E43, E52, F45.

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Non-technical summary

Public investment has been increasingly highlighted as an important policy tool because it stimulates the economy in the short run by increasing aggregate demand, while at the same time also improves the productive capacity of the economy in the long run, which increases aggregate supply. However, delivering public investment is often slow and subject to delays. These delays can be of a more procedural nature due to the delays in planning, but also technical, as it takes a long time to construct large projects that are typically done by governments.

We investigate the effects of these two frictions that cause delays in delivering public investment. The first friction, which we call a planning delay or a time-to-plan, is the period of time between the moment a public investment is announced and the time it starts being carried out. No material spending occurs during this time and therefore also no material stimulus to the economy other than information that something will be constructed and put to productive use in the future. The second friction, which we call construction delay or time-to-build, is the time that passes from the moment construction starts to when the project is delivered and put to use. During this time, there is an active demand stimulus to the economy provided by the government purchasing goods and services needed for government investment. Similarly as with the planning delay, this is accompanied by the information that, when finished, the investment project will be put to productive use in the future.

To assess the effects of delays related to public investment, we conduct a comparative analysis in two classes of models of a small open economy in a monetary union, calibrated to Ireland. One model features a standard labour market with sticky wages, while the other model is otherwise identical, but features search frictions and unemployment. We find that in both classes of models a permanent increase in (productive) public investment always leads to an increase in output, consumption, and exports in the long run. Delays in delivering public investment always result in lower welfare, even when the long-run increase in consumption and other variables is the same.

Moreover, we find that planing delays can make the stabilisation of business cycles more difficult. Planning delays can result in output decreasing in the short run, so that during a recession an announcement of an increase in public investment, if not followed quickly by implementation, can exacerbate the downturn. Moreover, if the eventual stimulus in the future coincides with a future boom in the business cycle, this may exacerbate the boom and overheat the economy.

1 Introduction

Public investment is an important policy tool (Ramey, 2021), because it has two distinct properties. First, it has short-term demand-side effects similar to those of government consumption, and can therefore be used to stimulate the economy in the short run. Second, public investment increases long-lasting public capital that has long-term supply effects similar as the productivity increase. Both properties have been increasingly recognised by policymakers as useful instruments to manage the economy, especially after the Great Recession (see, e.g., Coenen et al. (2012) and Coenen et al. (2013)), but also in the more strategic longer run. A very prominent recent example is the report of Mario Draghi (Draghi, 2024), which among other things calls for a structural reform in Europe with a permanent increase in public investment. However, the effect of public investment on the economy depends not only on the level of investment, but also on the efficiency with which it is delivered. Typically, delays happen (Leeper et al., 2010), so benefits from investment accrue further in the future.

We investigate the effects of two frictions related to public investment that cause delays. The first friction, which we call time-to-plan, is the time that passes between the moment a public investment is announced and the time it starts being carried out. The second friction, called time-to-build, is the time that passes from the moment construction starts to when the project is delivered and put to use. There is an important distinction between them. Time-to-plan implies an announcement of public investment in the future, but no (or minimal) spending and hence no immediate stimulus until investment commences. Time-to-build implies that the stimulus from the demand-side related to public investment is already taking place, but the project has not yet been finished and put to use, so that there are no supply-side effects from higher public capital yet.

Delays can happen in either phase. During the planning phase the frictions causing delays are typically of a more bureaucratic nature: there are zoning issues, various permissions must be obtained, there may be objections from the public, litigations, etc. These can be sizeable. For instance, in Ireland the time between a permission is obtained and construction commences can come close to two years in some regions (NCPC, 2024). Frictions causing delays in time-to-build are typically more technical and related to the organisation of work, supply lines, availability of workers, etc.

Regardless of the reason, both types of delays are a common occurrence when public investment is concerned (Leeper et al., 2010), and at the same time important for the short-term economic fluctuations that are caused by government investment (Ramey, 2021). While these authors focused on the closed economy, we analyse these issues in an open economy that is a member of a monetary union. This has two implications. First, monetary policy reaction is (almost) absent, as the economy is small relative to the rest of the monetary union. Second, the effects of domestic prices on external competitiveness, i.e., on exports and imports, play an important role.

Delays in delivering public investment, however, are particularly interesting because of its productive property, in the sense that it increases the stock of public capital, which in turn increases productivity of the private sector. The notion has a long tradition starting at least from Baxter and King (1993) and continuing in Leeper et al. (2010) and Ramey (2021). This increase in productivity of the private sector occurs in the future (when public capital is constructed and put in productive use). Therefore, it has very similar properties to a positive news shock about an increase in future productivity, which has an extensive literature on its own, starting with Beaudry and Portier (2006). The key issue in that literature was whether a standard model can generate a typical economic boom, with an increase in output, consumption, investment, and employment *immediately*, even if productivity will only increase in the future. Den Haan and Kaltenbrunner (2009) have pointed out that this can happen in a closed economy if there are search frictions. Den Haan and Lozej (2011) showed that this can also be the case in an open economy. The reason is that in a standard model with search frictions, employing a worker is essentially an investment decision on behalf of a firm. When deciding to post a job vacancy, a firm looks at the present value of future profits that will be obtained by employing an additional worker.

This intertemporal dimension of hiring is what makes delays in the delivery of public investment particularly interesting, because while delays shift the productivity into the future, firms may still hire workers now in anticipation of future profits. If this mechanism is strong, it may make delays in public investment less costly. This interaction of search frictions and public investment has, to the best of our knowledge, only been investigated in the context of a closed real economy model by Matusche (2025). The importance of analysing this in an open economy stems from the fact that a productive element of the public capital lowers marginal costs of domestic producers and therefore improves the external competitiveness of the economy. This channel is particularly important in small open economies.

We investigate the interaction of the two types of delays described above with the search frictions in the context of a large policy model of a small open economy in a monetary union.[1] To do so, we simulate a structural reform that leads to a permanent increase in public investment in a small open economy in Europe, Ireland, using a global model. We do so once in the standard setting, with no search frictions on the labour market, and once in the otherwise identical model, but where the standard labour market with staggered wage setting has been replaced by search frictions with staggered wage setting, closely following Gomes et al. (2023).

We find that a permanent increase in (productive) public investment always leads to an increase in output, consumption, and exports in the long run. Delays in delivering public investment always result in the benefits of higher output, exports and consumption occurring further in the future. In the case of planning delays, long delays can even result in output decreasing in the short run, implying that announcement of public investment in a recession, if not followed quickly by implementation, does not stimulate the economy. Moreover, it can lead to a fluctuation in the future that looks very much like a small business cycle. For example, if it coincides with a boom in the business cycle that is not related to public investment, this may exacerbate the boom and overheat the economy. In addition, the demand stimulus during the implementation phase of public investment worsens the external competitiveness of the economy.

We also find that in the model with search frictions there is some front-loading of news about the future, in the sense that output, private consumption, private investment and employment can increase initially despite delays, but the increases are typically quite small compared to the long-run effects. This implies that even if there are search frictions, delays in delivering public investment can be harmful (although less so than in the standard model).

[1] While we focus on Ireland (see Conefrey et al. (2024)), the issues of delays are general enough to apply to other small open economies in a monetary union.

2 Model

To conduct the analysis in a reasonably realistic modelling environment as used in policy institutions, we require a few features: (1) we need a small open economy that is a member of the monetary union; (2) we need a reasonable trade structure that approximates a modern global economy, where countries trade globally and not just within their currency area or a region; (3) we need a sufficient degree of real and nominal frictions, in particular sticky prices and sticky wages; (4) we need the fiscal policy that allows for public investment.

To satisfy these requirements, we use as the basic framework the model developed by Gomes et al. (2010) and Gomes et al. (2012), which features a small open economy in a monetary union, both integrated in a global economy.[2] To model the high degree of openness of the Irish economy as an export platform, we use the augmented framework of this model that features import-content of exports (Brzoza-Brzezina et al. (2014)), as this allows us to calibrate a realistic share of trade relative to GDP. The core model features four blocs, each of which is similar to a standard Smets-Wouters model with sticky prices and wages. Two of the blocs are in a monetary union, so that they share the same monetary policy rate and have the nominal exchange rate fixed to unity. The remaining two blocs are the US and the rest of the world. Risk-sharing is imperfect. Households can save in an intra-euro-area bond that is traded between the two blocs constituting the euro area. In addition, households can also hold an international bond (denominated in USD). These features of the core model satisfy conditions (1)-(2) and partly the condition (3), as the framework has the New Keynesian price and wage rigidities.

To satisfy condition (4), we use the augmented version that features public investment by Clancy et al. (2016) and Hickey et al. (2020). We call this our "first" version of the model and features a standard labour market with sticky wages. A more detailed description of this model is provided in Appendix A.[3]

The second version of the model is otherwise identical, but adds on top of sticky wage setting also search frictions in the labour market and unemployment. This feature is important, because it changes the firms' hiring decision from the frictionless per-period decision to an intertemporal choice. Its importance lies in the fact that if the public capital is productive, then an increase in public capital *in the future* plays a direct role in hiring in the labour market *immediately*, because the hiring decision is forward-looking. It is this feature that links the public investment literature (Baxter and King (1993) and Leeper et al. (2010)) with the news shock literature (Beaudry and Portier (2006), Den Haan and Kaltenbrunner (2009), Den Haan and Lozej (2011)). For an example of this linkage in a closed-economy model, see Matusche (2025).

The modelling of this second version of the model with labour market frictions has been based on De Walque et al. (2009) and Gomes et al. (2023). Their framework has been modified for the purpose of this paper to also include import-content of exports, public investment and public capital in the production function. A more detailed description of the model, in particular of its labour market is provided in Appendix B.[4]

[2]The core model is known as the EAGLE, which stands for the Euro Area and the GLobal Economy.

[3]For full details the reader should refer to Gomes et al. (2012) and Clancy et al. (2016).

[4]For full details the reader should refer to Gomes et al. (2012) and Gomes et al. (2023).

Here we reproduce the key equations related to public investment and the associated delays that are common to both versions of the model and that illustrate how the intertemporal dimension of public investment feeds into the public capital stock and into production and marginal costs. The latter feature is particularly important for small open economies, as it determines the effect of public capital on the external competitiveness of the economy.

Public investment, I_G, forms public capital, K_G, as follows:

$$K_{G,t} = (1 - \delta_G)K_{G,t-1} + I_{G,t-h}, \tag{1}$$

where δ_G is the depreciation rate of public capital, and h measures the time-to-build (in quarters) that is needed before public investment becomes part of public capital that is used in production (for instance, for 2-year time-to-build, h=8).

Government investment is decided by the government and follows an autoregressive process:

$$I_{G,t} = (1 - \rho)\overline{I_G} + \rho * I_{G,t-1} + \varepsilon_{I_G,t-j}, \tag{2}$$

where ρ measures the persistence of public investment, $\overline{I_G}$ is the steady state level of public investment, and ε_{I_G} is the change in public investment that is decided by the government. Index j measures the time to plan, i.e., the time from the announcement to the implementation of public investment (e.g., for 2-year time-to-plan, j=8). Throughout the paper, we assume that the announcement is fully credible.

Importantly, public capital improves the productivity of the private sector. In the context of both models, it enters in the production functions of tradable goods, $Y_{T,t}$, and non-tradable goods, $Y_{N,t}$, following the specifications that are standard in the literature (Baxter and King (1993) or Leeper et al. (2010)):

$$Y_{N,t} = z_{N,t}K_{G,t}^{\alpha_G}K_{N,t}^{\alpha_N}N_{N,t}^{1-\alpha_N} - \psi_N \tag{3}$$

$$Y_{T,t} = z_{T,t}K_{G,t}^{\alpha_G}K_{T,t}^{\alpha_T}N_{T,t}^{1-\alpha_T} - \psi_T, \tag{4}$$

where $z_{N,t}$ and $z_{T,t}$ are sector-specific productivities, $K_{N,t}$ and $K_{T,t}$ is capital used in each sector, and $N_{N,t}$ and $N_{T,t}$ is labour used in each sector. These equations show that an increase in public capital is the same as the increase in productivity (K_G enters production function in the same way as productivity z). The only difference is that productivity increase happens exogenously and is "free" in the sense that nobody has to pay for it, while the increase in public capital is a decision of the government and comes at a cost - the government must raise the required funds either by borrowing or by raising taxes. The analysis in this paper will assume that the government borrows the required funds.[5]

To understand the importance of productivity of public capital for the external competitiveness of the economy, recall that price is a markup over the marginal cost and that the marginal cost equation with public capital is (reproduced here for the tradable sector):[6]

[5]The borrowed funds are repaid over time by levying lump-sum taxes on households.

[6]The equation for marginal costs in the non-tradable sector is analogous.

$$MC_{T,t} = \frac{1}{z_{T,t} K_{G,t}^{\alpha_G} \alpha_T^{\alpha_T} (1-\alpha_T)^{1-\alpha_T}} r_{k,t}^{\alpha_T} w_t^{1-\alpha_T}, \tag{5}$$

where $r_{k,t}$ is the return on private capital and w_t is firms' cost of labour. Note that $K_{G,t}^{\alpha_G}$ appears in the denominator of marginal costs, so that an increase in public capital, if it is productive (which is the case when $\alpha_G > 0$), leads to a reduction in marginal costs and as a consequence to a reduction in prices and a depreciation in the real exchange rate.,

A delay in either planning or in construction of public investment goods will shift the increase in $K_{G,t}$ into the future and with it the decrease in marginal costs. Forward-looking agents in the model know this and react accordingly. However, their reaction must also take into account other frictions. In the standard model, this is the friction due to sticky wages, while in the search model, this is, in addition to sticky wages, also the search friction. To see how these frictions work, consider the following intuition for each of the models considered.

In the standard model, the wage setting is forward-looking, as unions set wages as a markdown over the marginal disutility of work (this is the standard Erceg et al. (2000) mechanism). Unions know that labour demand will increase when the demand for labour will increase, which will happen when government will start spending on investment. If wages were flexible, unions would increase wages then. However, when this increase in labour demand happens in the future (which is the case with planning delays), unions start increasing wages already now, because wages are sticky and it takes time to increase them. Faced with higher wages and no increase in goods demand before the stimulus begins, firms will reduce the number of workers.

In the search model, there is the aforementioned friction due to sticky wages, but also an additional search friction. Firms know that hiring takes time (unlike in the standard model, where hiring is instantaneous), so in order to satisfy the need for more workers in the future, they will have to start hiring already now. To see this, consider the optimality condition of the firm in the search model, which we reproduce below (see Appendix B for the details):

$$\psi_s = p_t^F \beta \frac{u'(c_{s,t+1})}{u'(c_{s,t})} \left[(1-\kappa_{w,s}) \mathcal{A}_t^F(w_{s,t+1}^*) + \kappa_{w,s} \mathcal{A}_t^F(w_{s,t+1}) \right]. \tag{6}$$

The condition states that a firm that is posting a vacancy for household type s equalises the per-period constant cost ψ_s for having a vacancy open with the expected value of getting a worker. This expected value depends on several factors. The first is the probability that the firm will find a worker, p^F. The remainder of the right-hand side of the equation 6 is the discounted value of the benefits that this firm will have from finding a worker. This depends on whether the firm will be able to renegotiate the wage with the worker or not. If $\kappa_{w,s}$ denotes the probability that a firm cannot renegotiate the wage for a newly hired worker from household type s, then the value of employing a new worker is, in monetary terms, equal to the weighted average of the value of a worker at a newly-renegotiated job $\mathcal{A}^F(w_{s,t}^*)$ and the value of a worker hired at average wage $\mathcal{A}^F(w_{s,t})$.[7] Because these values are forward-looking, they will increase immediately upon announcement, and firms will immediately post more vacancies, even if wages increase temporarily and if there is no immediate need for additional workers.

[7] Note that $\mathcal{A}^F(w_{s,t}^*) \equiv u'(c_{s,t}) A^F(w_{s,t}^*)$, and analogous for the value at average wage, see Appendix B.

3 Calibration

We calibrate both models to Ireland, the rest of the euro area (REA), the rest of the world (RW) and the US. First, we use the some standard values from the literature, but where available, we augment these with the empirical estimates. These are mostly based on the estimates for the euro area in Christoffel et al. (2008), and the values used in Gomes et al. (2012). Second, in addition to these standard values from the literature, we account for the fact that the neutral rate has followed a downward trend throughout and therefore adjust its level to be 1% in the steady sate (as in Gomes et al. (2023)). Finally, we update the trade matrix to account for the fact that trade flows have increased markedly from the levels before the Great Financial Crisis, and to account for the increased role of the global value chains, we also target the empirical levels of import-content of exports for all blocs in the model. Below we report the full set of values used in the calibration (please see A for the equations that correspond to the reported parameters).

Table 1 reports parameters used to calibrate utility and production functions. Parameters governing the utility function and intermediate goods production are mostly standard values from the literature. The productivity of public capital, α_G, was calibrated to be a conservative estimate from the literature (in the lower end of the range considered by Leeper et al. (2010), and lower than the estimates in Bom and Ligthart (2014), as Ireland is a developed economy and additional investment in infrastructure would likely be less productive than investment in infrastructure in countries where infrastructure is missing). Note also that the value of this parameter captures the average productivity of public investment, and there are arguably types of public investment that are more productive than the others. In such settings, the composition of public investment bundle matters. Our choice of relatively conservative value for this parameter can also be viewed as reflecting the view that that most productive types of public investment have been made first, and that the additional public investment - while still productive - is less productive that past public investment.[8]

Values for the calibration of final consumption good firms, final investment good firms, and re-exported goods are obtained as follows. First, the substitution elasticities are based on the values used in similar models (Christoffel et al. (2008), Gomes et al. (2012), and Clancy et al. (2016)). Second, the shares of goods are obtained by matching the openness of all blocs in terms of bilateral imports and import content of exports, with targets reported in Tables 2 and 3. In addition, net foreign assets are calibrated such that they match the trade balance. For the euro area, we assume a roughly balanced trade balance, for the US a 5% deficit, for Ireland, we target about 15% surplus in the steady state. The latter is a difficult statistic to match, as trade balance has fluctuated between almost zero and as much as 40% in recent years (2000-2024). To obtain a reasonable number that is approximately in line with the trade balance to GNI* ratio over the recent years, we opt for the relatively large surplus. Note, however, that due to large foreign direct investment to Ireland, the large negative value of net foreign assets and the corresponding need for a large trade surplus are not unexpected. A similar issue as with the trade balance is with the level of imports and exports, which often exceed GDP. Since 2000, Irish imports have fluctuated between 65% and 124% of GDP. We have opted for the calibration that targets Irish import-to-GDP ratio of about 75%,

[8] For an analysis how productivity of public investment affects the responses of the economy, see e.g. Hickey et al. (2020).

which corresponds to the period before the one-off GDP increase in 2015.[9] The main implication of the calibration of large trade surplus and low net foreign assets for Ireland is that we are able to obtain a relatively low consumption-to-GDP ratio, which is in line with the Irish data.

[9]In 2015, Irish GDP increased by 25% due to several reasons, but the main factor was that intangible assets of several multinationals have been transferred to Ireland, and with them also the revenues pertaining to these assets. For the dynamic results reported in this paper, the exact value of the great ratios does not make a material difference, but it does help the credibility of the model.

TABLE 1. Calibration of households and firms

	Home	REA	US	RW
Households				
Discount factor (β)	0.9975	0.9975	0.9975	0.9975
Intertemporal elasticity of substitution (σ)	1.00	1.00	1.00	1.00
Habit persistence (κ)	0.6	0.6	0.6	0.6
Capital depreciation rate (δ^K)	0.025	0.025	0.025	0.025
Share of non-Ricardian households (ω)	0.25	0.25	0.25	0.25
Interm.-good firms (trad. and non-trad. sectors)				
Subst. btw. labour and capital	1.00	1.00	1.00	1.00
Bias towards capital - tradables (α_T)	0.30	0.30	0.30	0.30
Bias towards capital - non-tradables (α_N)	0.30	0.30	0.30	0.30
Production - public capital (α_G)	0.05	0.05	0.05	0.05
Production - labour services (α_H)	0.9	0.9	0.9	0.9
Final consumption-good firms				
Subst. btw. domestic and imported trad. goods (μ_{TC})	2.50	2.50	2.50	2.50
Bias towards domestic tradable goods (ν_{TC})	0.30	0.47	0.63	0.71
Subst. btw. tradables and non-tradables (μ_C)	0.50	0.50	0.50	0.50
Bias towards tradable goods (υ_C)	0.80	0.45	0.35	0.35
Bilat. bias towards imported goods, Home (ν_{MC})	-	0.24	0.12	0.64
Bilat. bias towards imported goods, REA (ν_{MC})	0.07	-	0.10	0.83
Bilat. bias towards imported goods, US (ν_{MC})	0.04	0.12	-	0.84
Bilat. bias towards imported goods, RW (ν_{MC})	0.04	0.58	0.38	-
Substitution btw. consumption good imports (μ_{IMC})	2.50	2.50	2.50	2.50
Final investment-good firms				
Subst. btw. domestic and imported trad. goods (μ_{TI})	2.50	2.50	2.50	2.50
Bias towards domestic tradable goods (ν_{TI})	0.36	0.65	0.79	0.76
Substitution btw. tradables and non-tradables (μ_I)	0.50	0.50	0.50	0.50
Bias towards tradable goods (ν_I)	0.80	0.75	0.75	0.75
Bilat. bias towards imported goods, Home (ν_{MI})	-	0.17	0.41	0.42
Bilat. bias towards imported goods, REA (ν_{MI})	0.03	-	0.23	0.74
Bilat. bias towards imported goods, US (ν_{MI})	0.05	0.15	-	0.80
Bilat. bias towards imported goods, RW (ν_{MI})	0.01	0.50	0.49	-
Substitution btw. investment good imports (μ_{IMI})	2.50	2.50	2.50	2.50
Reexported goods				
Subst. btw. dom. tradables and imported exports (μ_X)	1.50	1.50	1.50	1.50
Bias towards domestic tradable goods in exports (ν_X)	0.55	0.66	0.82	0.63
Bilat. bias towards imported goods, Home (ν_{MX})	-	0.23	0.20	0.57
Bilat. bias towards imported goods, REA (ν_{MX})	0.07	-	0.13	0.80
Bilat. bias towards imported goods, US (ν_{MX})	0.05	0.13	-	0.82
Bilat. bias towards imported goods, RW (ν_{MX})	0.03	0.56	0.41	-
Substitution btw. goods in import bundle (μ_{MX})	2.50	2.50	2.50	2.50

Note: REA=Rest of euro area; US=United States; RW=Rest of world

TABLE 2. Steady-state national accounts (ratio to GDP, %)

	Home	REA	US	RW
Domestic demand				
Private consumption	46.9	56.4	66.1	54.9
Private investment	16.25	17.41	16.25	19.25
Public consumption	18.80	23.10	19.40	20.60
Public investment	3.0	3.0	3.0	3.0
Trade				
Imports (total)	75.7	23.5	13.8	9.3
Imports of consumption goods	29.2	12.7	9.5	3.9
Imports of investment goods	9.6	4.4	3.0	2.4
Imports of exports	37.0	6.4	1.3	3.0
Net foreign assets (ratio to annual GDP)	-20.0	-0.1	-	-3.0
Trade balance (ratio to annual GDP)	15.0	0.1	-4.8	2.2
Share of world GDP	0.026	16.44	22.6	60.7

Note: REA=Rest of the euro area; US=United States; RW=Rest of world

TABLE 3. International Linkages (Trade matrix, share of domestic GDP, %)

	Home	REA	US	RW
Consumption-good imports				
Total consumption good imports	29.2	12.7	9.5	3.9
From partner				
Home	-	0.5	0.2	0.1
REA	6.4	-	1.0	2.4
US	2.8	1.0	-	1.4
RW	20.0	11.2	8.3	-
Investment-good imports				
Total investment good imports	9.5	4.4	3.0	2.4
From partner				
Home	-	0.1	0.1	0.0
REA	1.6	-	0.4	1.3
US	3.5	0.8	-	1.1
RW	4.4	3.5	2.5	-
Imports of exports				
Total imports of exports	37.0	6.4	1.3	3.1
From partner				
Home	-	0.3	0.0	0.1
REA	7.8	-	0.2	1.8
US	6.2	0.7	-	1.2
RW	23.0	5.4	1.1	-

Note: REA=Rest of the euro area; US=United States; RW=Rest of world

The set of parameters governing the pricing block of the model consist of firm markups (Table 4), nominal price rigidities (Table 5), and parameters of monetary policy rules (Table 6). The calibration of these parameters in the model follows the parameterisation estimated in Christoffel et al. (2008), and the values used in Gomes et al. (2012).

TABLE 4. Price markups (elasticities of substitution)

	Tradables (θ_T)	Non-tradables (θ_N)	Imports of exports (θ_X)
Home	1.20 (6.0)	1.50 (3.0)	1.30 (4.3)
REA	1.20 (6.0)	1.50 (3.0)	1.30 (4.3)
US	1.20 (6.0)	1.28 (4.6)	1.20 (6.0)
RW	1.20 (6.0)	1.28 (4.6)	1.20 (6.0)

Note: REA=Rest of the euro area; US=United States; RW=Rest of world

TABLE 5. Nominal price rigidities

	Tradables (ξ_T)	Non-tradables (ξ_N)	Imports of exports (ξ_X)
Home	0.75	0.75	0.75
REA	0.92	0.92	0.75
US	0.75	0.75	0.75
RW	0.75	0.75	0.75

Note: REA=Rest of the euro area; US=United States; RW=Rest of world

TABLE 6. Monetary policy

	Weight on inflation (ϕ_π)	Weight on output growth (ϕ_Y)	Int. r. persistence (ϕ_r)
Home	1.70	0.10	0.87
REA	1.70	0.10	0.87
US	1.70	0.10	0.87
RW	1.70	0.10	0.87

Note: REA=Rest of the euro area; US=United States; RW=Rest of world

To calibrate the model with labour market frictions, we use the following strategy. First, we use identical parameters as in the model without labour market frictions (discussed above) wherever possible, in order to keep the two model versions harmonised to the greatest extent possible so that they are comparable. We can do this only for those parameters that are common to both models, such as the Frisch elasticity of labour supply and the frequency of resetting prices (see Table 5 for nominal price rigidities that are common across models) and wages. Second, for parameters that are specific to the model with search frictions, we use the values based either on the literature or empirical estimates. The calibration parameters are reported in Table 7 and we discuss both groups of parameters below in more detail.

In the first group of parameters that we can harmonise across both models are wage rigidities and Frisch labour supply elasticities. The Frisch labour supply elasticity is set to 0.5 as is typical in the literature (its inverse, $\zeta = 2$). Even though the model with labour market frictions can distinguish between wage rigidities of new hires and wage rigidities of existing workers (measured by the probabilities that they start working at existing average wage), we set both to equal value (and to the value equal to that in the model with the standard labour market), so that $\xi_{w,i} = \xi_{w,j} = \kappa_{w,i} = \kappa_{w,j}$. These values are based on the estimates in De Walque et al. (2009).

In the second group of parameters that are not shared between both models, we set matching elasticities for both households to 0.5, in line with the range of values in Petrongolo and Pissarides (2001). We do this because we want to keep the model with search frictions as harmonised as possible with the standard model, which does not distinguish the labour market for different groups of households. The parameter governing the production of labour services is in line with Bodart et al. (2006).

Matching efficiency and vacancy posting costs are obtained by targeting matching probabilities of workers and firms. Matching probabilities of workers come from the OECD and Eurostat data for unemployment duration by educational attainment for 2017 and 2018 using the method of Shimer (2012).[10] The matching probability for firms is based on the estimates for the US in Den Haan et al. (2000) and Stähler and Thomas (2012) for Europe. These two probabilities determine matching efficiency and (indirectly) vacancy posting costs (the latter being lower for HtM households).

Separation rates are obtained by matching unemployment rates, which are OECD data averages from 2004-2019. Consistently with job finding probabilities, we assume that the unemployment rate for non-Ricardian households is the unemployment rate for persons with educational attainment below upper-secondary. Matching the unemployment rates results in break-up rates for HtM households exceeding those of Ricardian households. Bargaining power has been set to 0.5, for both groups of households, in line with the literature.

To harmonise the models, we match the wage and total labour services from the search model with those in in the standard model. To match the wage, we use the replacement ratio in the search model (this indirectly influences wage through the workers' outside option). This results in replacement ratios that are close to the OECD estimates for Ricardian and HtM households, which are typically around 0.5 and slightly higher for the HtM households.[11] To match labour services, we use the total time endowment of households.

[10]As described in Gomes et al. (2023) and Herman and Lozej (2023), we assume that non-Ricardian households have below upper-secondary education and Ricardians have above upper secondary education. The estimates are population-weighted across countries.

[11]Concretely, replacement rates for one-year horizon of unemployment duration for Ricardian households and two-year horizon of unemployment duration for non-Ricardian households, given that they are more likely to be long-term unemployed.

TABLE 7. Calibration of the labour market

	Home	REA	US	RW
Inverse of the Frisch elasticity of labour supply (ζ)	2.00	2.00	2.00	2.00
Matching probability, Ricardian workers, (p_i^W)	0.3021	0.2238	0.5292	0.3442
Matching probability, HtM workers, (p_j^W)	0.2090	0.1848	0.5385	0.2598
Matching probability, firms, (p_s^F)	0.70	0.70	0.70	0.70
Matching efficiency, Ric. w., $(\varphi_{i,M})$	0.4598	0.3958	0.6086	0.4908
Matching efficiency, HtM w. ,$(\varphi_{j,M})$	0.3825	0.3596	0.6139	0.4264
Vac. posting cost, Ric. w.,(Ψ_i)	0.6984	0.3336	0.3126	0.3715
Vac. posting cost, HtM w., (Ψ_j)	0.2373	0.1953	0.1384	0.2630
Break-up rate, Ric. w., $(\delta_{x,i})$	0.0140	0.0226	0.0271	0.0221
Break-up rate, HtM w., $(\delta_{x,j})$	0.0339	0.0276	0.0516	0.0259
Disutility of labour, Ric. w., (χ_i)	1.0270	0.6101	0.5838	0.6677
Disutility of labour, HtM w., (χ_j)	1.2732	1.3434	1.3845	1.2745
Matching elasticity, Ric. w., (μ_i)	0.50	0.50	0.50	0.50
Matching elasticity, HtM w., (μ_j)	0.50	0.50	0.50	0.50
Bargaining power (η)	0.50	0.50	0.50	0.50
Replacement ratio, Ric. w., $(rrat_i)$	0.470	0.525	0.463	0.495
Replacement ratio, HtM w., $(rrat_j)$	0.597	0.551	0.542	0.542
Unemployment rate, (un)	0.0696	0.1038	0.0605	0.0694
Unemployment rate, HtM w., (un_j)	0.1437	0.1334	0.0918	0.0930
Prob. to renegotiate existing wage, Ric. w., $(\xi_{w,i})$	0.8879	0.8879	0.8879	0.8879
Prob. to renegotiate existing wage, HtM w., $(\xi_{w,j})$	0.8879	0.8879	0.8879	0.8879
Prob. to start job at avg. wage, Ric. w., $(\kappa_{w,i})$	0.8879	0.8879	0.8879	0.8879
Prob. to start job at avg. wage, HtM w., $(\kappa_{w,j})$	0.8879	0.8879	0.8879	0.8879

Note: REA=Rest of the euro area; US=United States; RW=Rest of world

4 Simulation design and results

To analyse the effects of delays in the delivery of public investment, we simulate a gradual, but permanent debt-financed increase in public investment. To clearly separate the effects of different types of delays, we simulate the increase in public investment without any delays, and then compare this with 2- and 5-year planning delays (time-to-plan). We then repeat the same simulation, but with 2- and 5-year construction delays (time-to-build).[12] We conduct the same set of simulations across two models, first in the model without search frictions on the labour market, and second in the otherwise identical model, except that this time the standard labour market is replaced by search frictions.[13]

It is important to clarify in detail the information structure of the experiments conducted. Before the announcement, the economy is in the steady state, and the

[12]Note that while the model has a steady-state 2% inflation, we assume that government investment spending is in real terms, as this allows us to compare shocks of the same size across time. In all cases we assume the government borrows when it invests, i.e., there is no front-loading in government borrowing.

[13]See Appendix A and Appendix B for details of the models.

announcement of public investment is a surprise. The announcement is fully credible, the time path of public investment is known at the time of the announcement, and this includes the delays (planning or construction). Note that in this setting a surprise in the sense of the delay being longer than initially announced could be inferred from the charts shown below as the difference between the impulse responses in the charts. For instance, the effect of a 2-year delay, when the initial expectation is immediate implementation, could be computed as the difference between two corresponding impulse responses (this would be exact in a linear model, but is only approximate in our nonlinear setting).[14]

4.1 Delays in delivering public investment in a standard model

Figure 1 shows the effects of the delays in planning, and Figure 2 shows the effects of the delays in construction (time-to-build) in the standard model without search frictions. In each figure, the top-left chart shows the path of public investment, and the adjacent chart shows the path of the public capital stock. The path of public capital is the same in both figures, as the source of the delay in public investment does not matter for the stock of the public capital (only the delay itself matters). The key difference, therefore, between planning and construction delays is in the timing when the outlays of funds and the associated payments for public investment goods occur.

This timing of events matters. In Figure 1, the planning delay leads to a period of time where agents in the economy know that public investment will happen in the future, but there is no demand or supply stimulus from public investment yet, because the expenditure has not yet occurred due to the planning delay. Such a planning delay is equivalent to an announcement effect of future outlays for public investment (and future increase in productivity due to higher stock of productive public capital).[15]

Figure 1 shows three cases. The black line shows the case when public investment increases without any delay. This is the typical way public investment is analysed in standard cases that do not deal with delays, and therefore serves as a useful benchmark. The dashed red line shows the 2-year delay in planning, and the dotted blue line shows the 5-year delay in planning. Compared to the benchmark case when the stimulus occurs at the announcement, the delays in planning result in output falling slightly during the planning period, with the decrease being larger, the longer is the planning delay. Inflation increases upon announcement and also later in the future (when the demand stimulus occurs), and it remains elevated during the planning period. This is because during this period private consumption increases, and so does (mildly) private investment. The decline in output in the case of delays is due to the fall in net foreign demand, which is primarily caused by the decrease in exports and an increase in imports. Output starts to increase only after the stimulus begins and afterwards, and inflation falls further out in the future, when the demand stimulus eases and the supply effects from higher public capital prevail (recall that public capital is productive). The fluctuations in prices affect

[14] In a linear model, the starting point of the simulation does not matter, but in a nonlinear model it does. However, the model is not very nonlinear and the movement away from the initial steady state is not large in the first few years, which makes the effect of the nonlinearity very small.

[15] We do not consider the case where the possibility of delays affects the sentiment or increases uncertainty in the economy, which is beyond the scope of this paper.

the external competitiveness of the economy, which is reflected in exports and imports, with exports decreasing when prices increase. Exports recover only in the medium to long run when the supply-side effects of productive public capital reduce marginal costs and hence inflation, which restores and improves external competitiveness. Private investment initially increases, then decreases in the medium term, and recovers in the longer run.[16] Labour falls if there is a planing delay, and the fall is more pronounced the longer the delay is. This happens because households anticipate the increase in resources in the future and increase their consumption. The wealth effect reduced the supply of labour and this leads to an increase in wages. Firms, observing the increase in wages, reduce the demand for labour (and increase the demand for capital, causing an increase in investment), as labour becomes less attractive due to higher wages.[17]

In the long run, shown in Figure 1 as the dot on the extreme right-hand side of the plots, the benefits of higher public investment are obvious. Output, consumption, private investment and wages all increase. There is a permanent decrease in labour services, caused by a reduction in labour supply by households. This happens despite the increase in public debt (recall that the increase in public investment is debt-financed), because higher public capital implies larger productivity and more available resources, which compensates for higher taxes needed to finance higher level of public investment.[18]

Note that the paths of inflation and to some extent output look very much like a standard business cycle that was caused by first a negative and then a positive supply shock. However, this behaviour is caused by only one (demand) shock and the effect of its announcement. Moreover, the longer the delay, the more pronounced the fluctuation is, and the cycle is longer (the increase is shifted further into the future when planning delays are longer). From the policy perspective, this can be problematic, because the state of the future business cycle is unknown when the public investment is announced. For instance, suppose an economy is in a recession and the government announces an increase in investment. Because of planning delays, this investment occurs in the future, when the economy may already be out of the recession and in a boom, which risks overheating the economy. Moreover, our results imply that announcing an increase in public investment during the recession will not help stimulate the economy in a counter-cyclical manner if there are long planning delays - note that output decreases during the planning phase. This implies that an increase in public investment during a downturn will help only if public investment is increased without delay.

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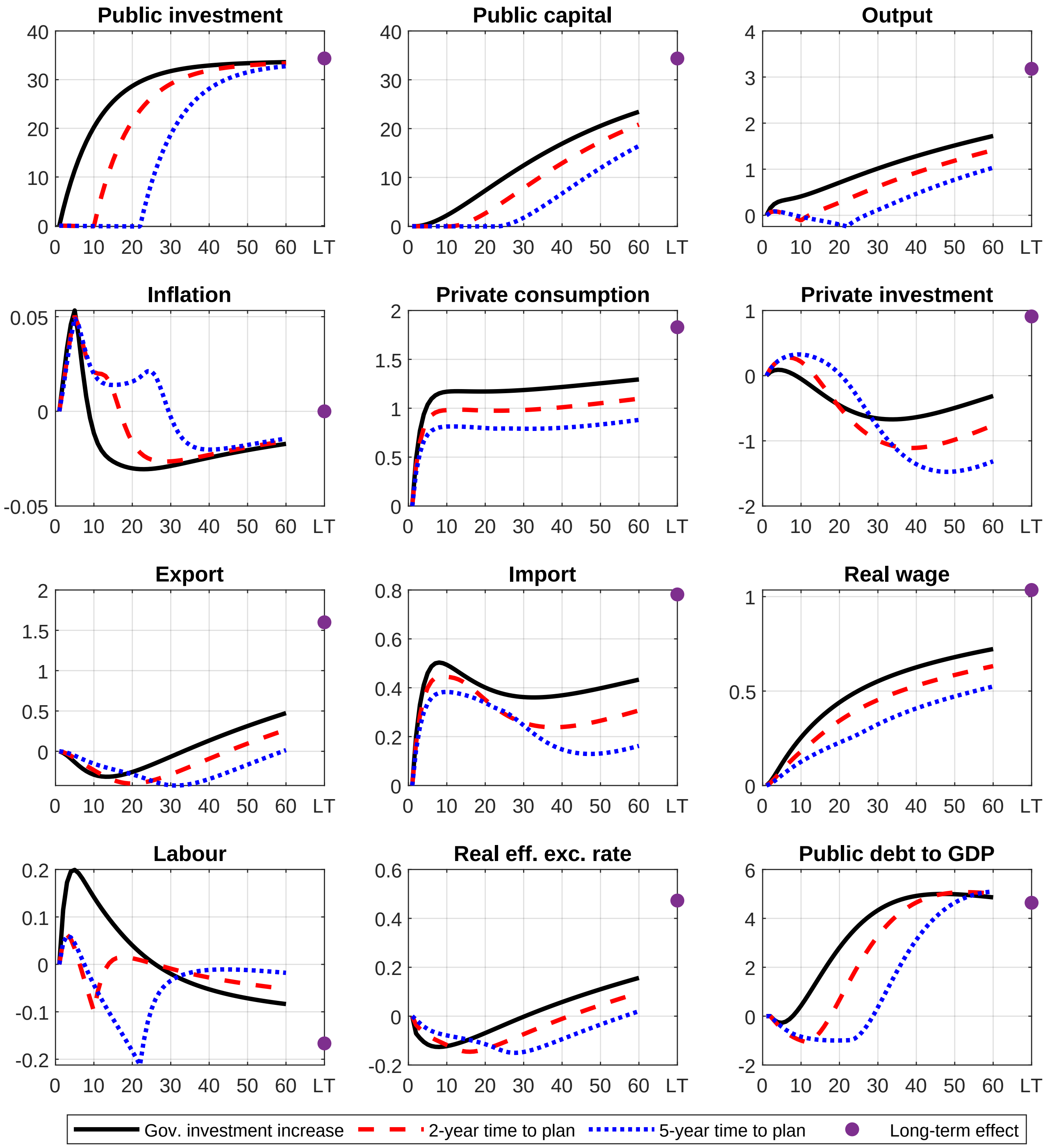
[16]The response of private investment is not robust and depends on the response of wages, with investment increasing if wages are more rigid.

[17]Note that this mechanism is different than it would be in an RBC model, where labour would decrease because of the decrease in labour supply. Here, labour decreases because of the decrease in labour demand caused by higher wages (which are in turn caused by lower labour supply).

[18]We assumed taxes are lump-sum, i.e., not distortionary. With distortionary taxes, this would not necessarily be the case, depending on the type of taxes used, see Hickey et al. (2020).

FIGURE 1. Standard model: Permanent increase in public investment with planning delays



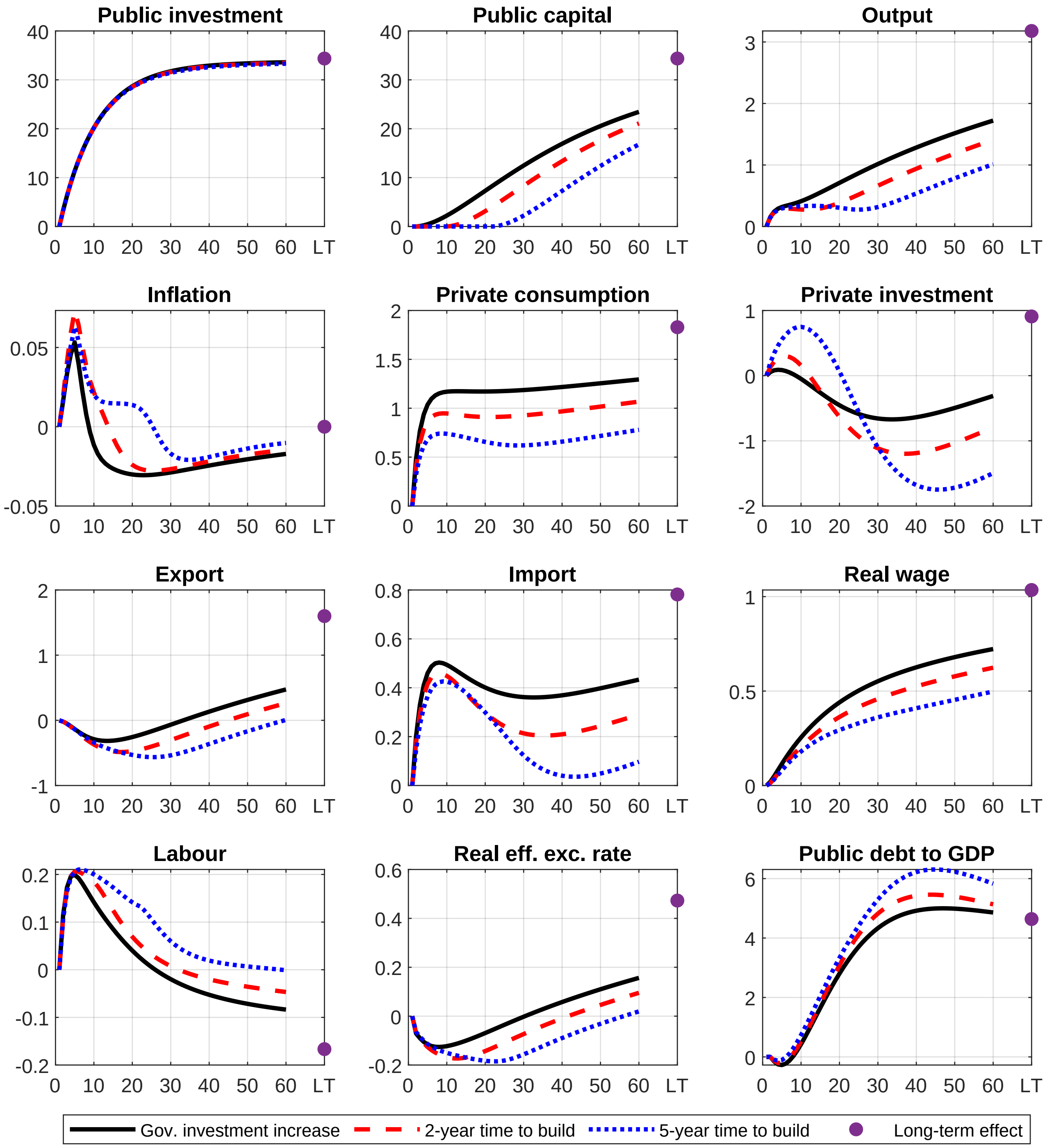
Horizontal axes: quarters; vertical axes: percent deviations from the steady state, except inflation, which is in annualised p.p. deviations from the steady state, and public debt to GDP, which is in p.p. deviations. All variables are in real terms.

Figure 2 shows delays due to construction (time-to-build). As before, the benchmark case, where there are no construction-related delays, is shown in black line and serves as the benchmark against which to compare the two cases with delays. Dashed red line shows 2-year construction delay, and the dotted blue line shows the 5-year construction delay. Delays related to construction are less problematic than planning from the perspective of short-term business cycle management, because the demand stimulus occurs immediately in all cases (top left panel) and output starts increasing already on impact. However, the strength of the stimulus and the increase in output are slower the longer it takes to complete the project, because the supply-side benefits from higher public capital kick in later. In particular, inflation stays higher for longer when the construction delays are long, which exacerbates and prolongs the real exchange rate appreciation (a fall in the real effective exchange rate means appreciation) and is detrimental for (net) exports.

Unlike in the case of planning delays, labour increases despite the increase in wages. This is because there is an immediate stimulus from higher demand for public investment goods, which have to be produced, and this increases the demand for labour despite higher wages (and pushes wages up slightly more in the initial phases than in the case of planning delays). Private investment increases in the short run because there are more resources available (from higher output) and because firms wish to supplement the increase in labour with more capital. The longer the delay, the stronger is the initial increase in labour. This is because private consumption increases by less initially, and therefore labour supply decreases by less. This leads to a lower increase in wages, which stimulates the demand for labour by firms. In the long run (shown as dots on the right axis of each plot), all responses are identical to the responses after a planning delay.

From the business cycle management perspective, construction delays may be less problematic, because the demand stimulus from higher public investment occurs immediately and there are no swings in the opposite direction in economic activity, unlike in the planning delays case.

FIGURE 2. Standard model: Permanent increase in public investment with construction delays



Horizontal axes: quarters; vertical axes: percent deviations from the steady state, except inflation, which is in annualised p.p. deviations from the steady state, and public debt to GDP, which is in p.p. deviations. All variables are in real terms.

4.2 Delays in delivering public investment in a model with search frictions

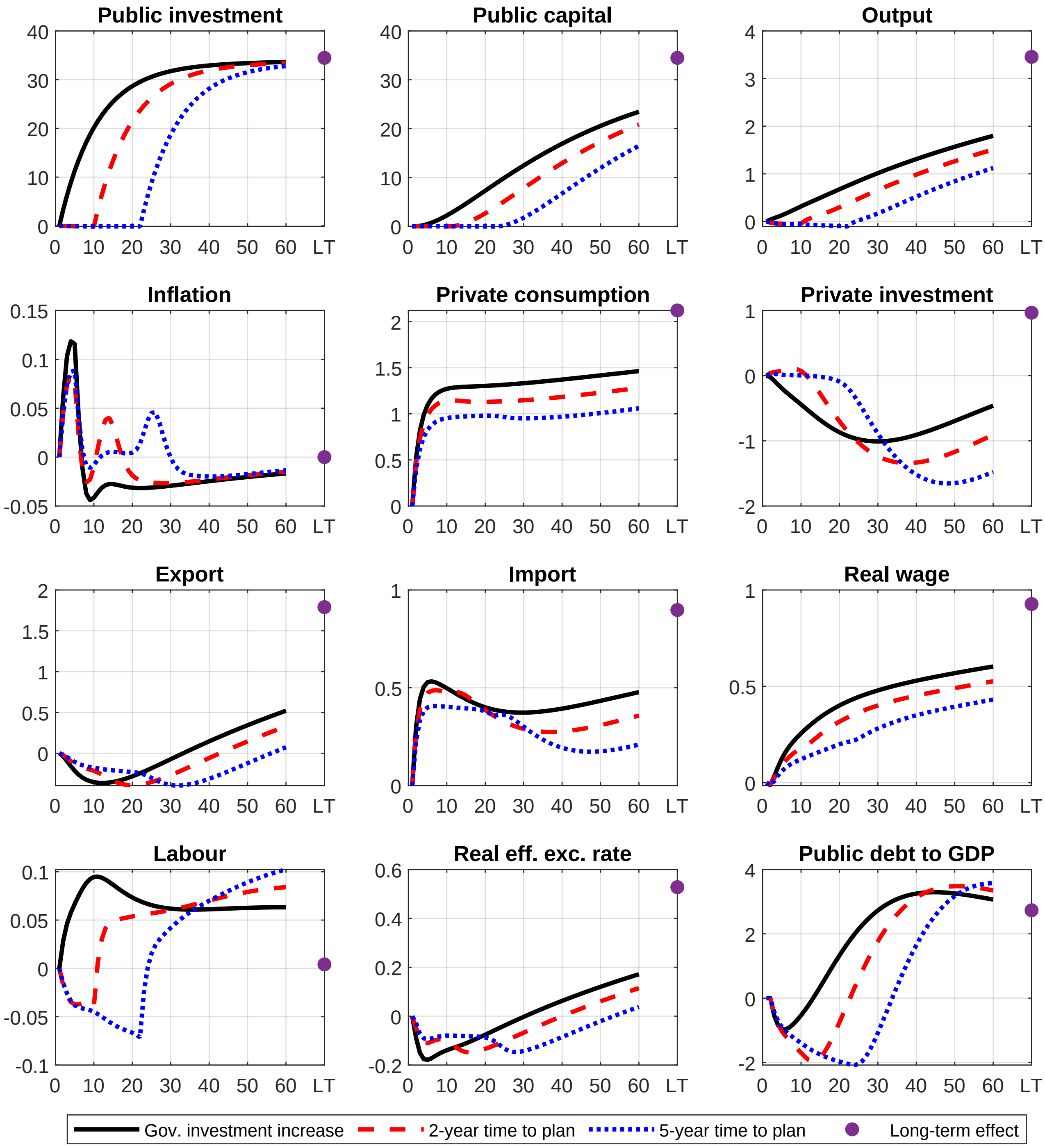
As explained above, due to the fact that the decision to hire a worker is forward-looking in a model with search frictions, one would expect that delays in the delivery of public investment are less detrimental in the short run. Forward-looking firms anticipate the increase in future productivity regardless of the delay (it is just shifted farther in the future), and because it takes time to hire workers, they start hiring workers already now. This brings some of the benefits of higher future productivity forward. Figure 3 indicates that there is indeed some evidence of such a channel. Labour increases during the planning phase, if the planning phase is not too long, and decreases by less than in the standard model if the planning phase is long. The outcomes for output are similar, with output mildly increasing during the delay phase for short delays, and remaining practically unchanged for longer delays.

Private consumption increases for the same reason as in the standard model, i.e., an expected long-run increase in available resources due to the higher level of productive public capital. Private investment increases by less than in the standard model during the delay phase because labour does not decrease as much and a greater share of aggregate demand can be met in production using labour. Wages increase, but less than in the standard model because labour increases (or falls by less than in the standard model). As a result, output increases during the planning phase.

Inflation also increases already on impact and tends to stay above zero until the outlays for public investment begin, when it increases again. The initial increase in inflation is due to higher demand that has not been met by the increase in quantities supplied. The initial increase in inflation quickly disappears as supply increases, which is in part due to new hiring being brought forward. As explained in Section 2, new hiring in the search model does not depend only on wages, but also on the probability that a firm will be able to find a worker, which takes time. Firms therefore start hiring immediately when there is news about the needs for workers in the future, as long as that future is not too far away. This can clearly be seen if a 2-year delay and a 5-year delay are compared. When the delay is short, firms increase hiring, while if the delay is longer, firms still decrease hiring, although not as much as in the standard model. We further explore this issue in the next section.

Note also that the long-run effects of increasing public investment in the search model are somewhat larger than in the standard model. This happens because in the long run, labour increases (note that labour fell in the long run in the standard model), which happens because labour demand effect from higher level of public capital dominates the negative labour supply effect. Higher stock of productive public capital increases the value of each worker for the firm, and this increase is permanent. In the long run, firms increase the level of vacancies, and this implies more hiring of workers (lower long-run unemployment). While households still reduce the per-capita hours worked, the effect of hiring (extensive margin) dominates the effect of hours (see also next section).

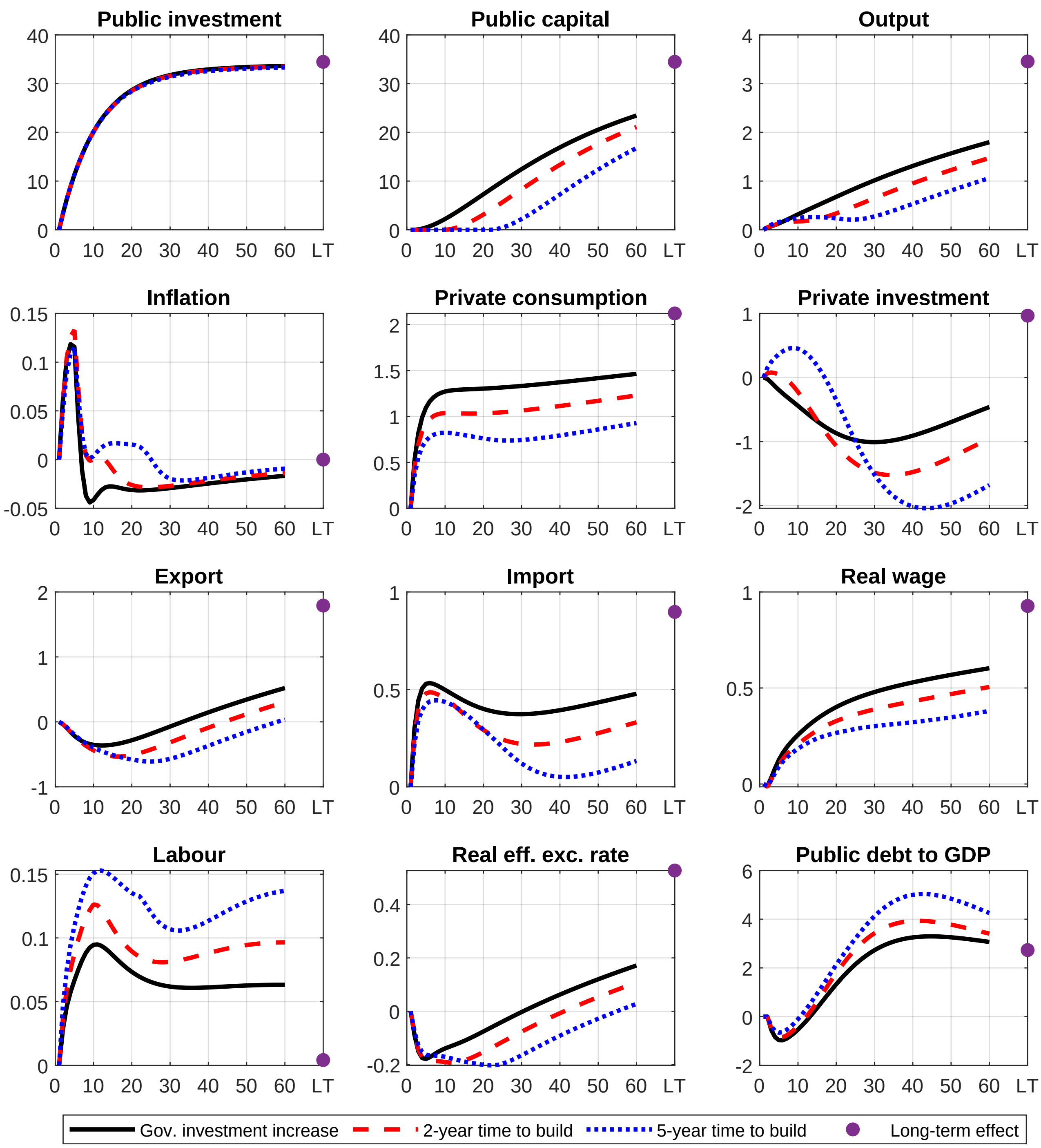
FIGURE 3. Search frictions: Permanent increase in public investment with planning delays



Horizontal axes: quarters; vertical axes: percent deviations from the steady state, except inflation, which is in annualised p.p. deviations from the steady state, and public debt to GDP, which is in p.p. deviations. All variables are in real terms.

The mechanism is somewhat, but not completely, similar when the delays are due to construction (time to build), shown in Figure 4. In particular, inflation increases markedly already on impact, and it does so regardless of the length of the delay. This is the consequence of the stronger wage increase, as outlays for public investment (and therefore the increase in labour demand and employment) happen immediately, regardless of the time needed to construct public capital. High inflation worsens the external competitiveness of the economy through the real effective exchange rate appreciation and the resulting fall in exports. This is worse, the longer the delay lasts, because the positive supply-side effect of public capital occurs later in the future.

FIGURE 4. Search frictions: Permanent increase in public investment with construction delays



Horizontal axes: quarters; vertical axes: percent deviations from the steady state, except inflation, which is in annualised p.p. deviations from the steady state, and public debt to GDP, which is in p.p. deviations. All variables are in real terms.

4.3 The role of search frictions in labour market volatility

In the preceding analysis, both models were harmonised so that the steady state of both models was identical. In addition, the Hosios condition Hosios (1990) has been imposed, so that the real friction due to search should be neutralised in the steady state.[19]

In this section, we explore the role of search frictions and labour market volatility on the outcomes of the permanent increase in government investment. We do so by exploiting the findings of Hagedorn and Manovskii (2008), who show that - in the presence of sticky wages - a smaller labour firm surplus helps overcome the Shimer puzzle (Shimer, 2005).[20] By lowering the labour firm surplus, we can investigate whether making the labour market more reactive in terms of the extensive margin materially affects the outcomes of our experiment. We consider three cases: the benchmark case that we compared with the standard model above, a case with labour firm surplus halved (we call it a "Low surplus" case), and a case with labour firm surplus of approximately 20% of the surplus in the benchmark case ("Very low surplus" case)[21]

The reason why this experiment is interesting is because a delayed increase in (productive) public investment is akin to a news shock about future productivity, which has been a subject of a number of papers in the past, both in terms of empirics (Beaudry and Portier (2006)) and theory (Jaimovich and Rebelo (2009), Den Haan and Kaltenbrunner (2009), Den Haan and Lozej (2011)). One of the main issues in that literature was whether a news shock about future productivity can cause a so-called Pigou cycle, where output, consumption, investment, and labour jointly increase in the period before the shock materialises. In our setting, this question is particularly interesting when we have planning delays, because such a delay is closest to a news shock: households and firms find out today that productive public capital will be higher in the future, but only after some time. During this time there will be no demand stimulus because of the planning delay (construction delay is different, as there *is* a demand stimulus during this period; we consider this case in Appendix C).

The results of planning delays with varying degrees of search frictions are shown in Figures 5 and 6. Figure 5 shows the main macroeconomic aggregates and Figure 6 shows the main labour market variables. In each figure, the first column shows the benchmark results and the remaining two columns show the results of alternatives. First, note that in the benchmark case, there is no "Pigou cycle", as output and labour services (the latter due to the fall in hours worked) do not increase during the delay period, and the increase in private investment is meager. If the labour market is more volatile than in the benchmark case, then we do observe a small increase in output and labour services (the

[19]Note that our model features the choice of hours worked (see Appendix B, in particular equation 70). Because in equation 70 α_H is less than 1, the hours production function is concave, and the marginal revenue for the firm from an additional hour supplied is $\alpha_H x_{s,t}(h_{s,t})^{\alpha_H - 1}$. This nonlinearity matters, see e.g. Kudoh and Sasaki (2011) or Mangin and Julien (2021). In the model used here, this nonlinearity is not very strong, as α_H is already close to 1.

[20]Recall, Shimer (2005) pointed out that a standard search model has difficulties generating realistic volatility in unemployment and vacancies.

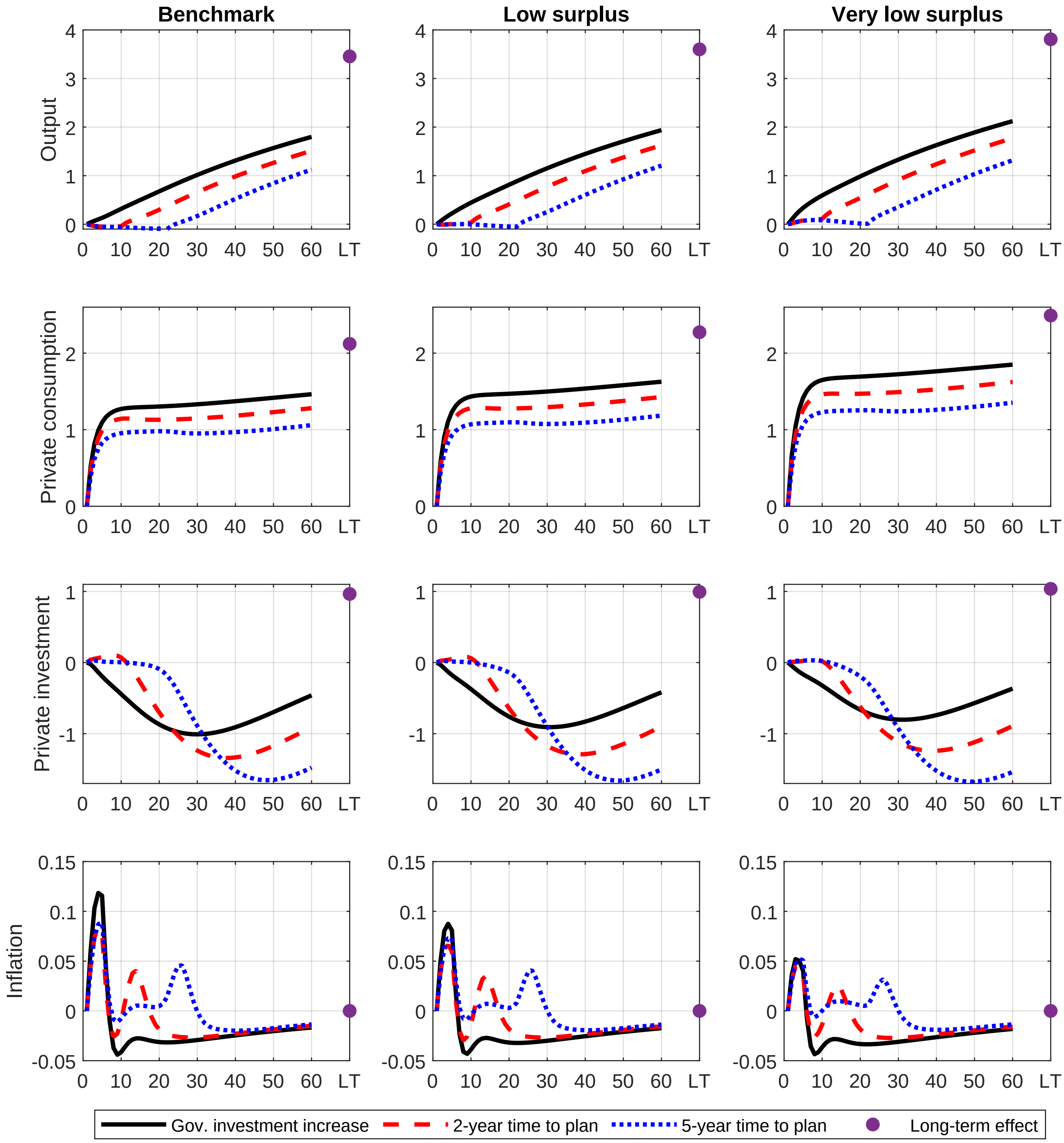
[21]We implement the lowering of surplus by raising the number of hours worked in the steady state towards 1, which reduces the labour firm's surplus, as it reduces the margin it earns from buying labour from households and selling it to intermediate goods firms.

number of hires dominates the fall in hours), while investment response lingers slightly above zero during the delay phase. Consumption increases in all cases.[22]

Inflation fluctuations are also lower when the labour market is more volatile. The reason for this is that a more volatile labour market implies more hiring, which dominates the reduction in hours worked per capita (see Figure 6). More responsive labour supply during the delay reduces wage increase and therefore dampens the increase in marginal cost of firms and inflation.

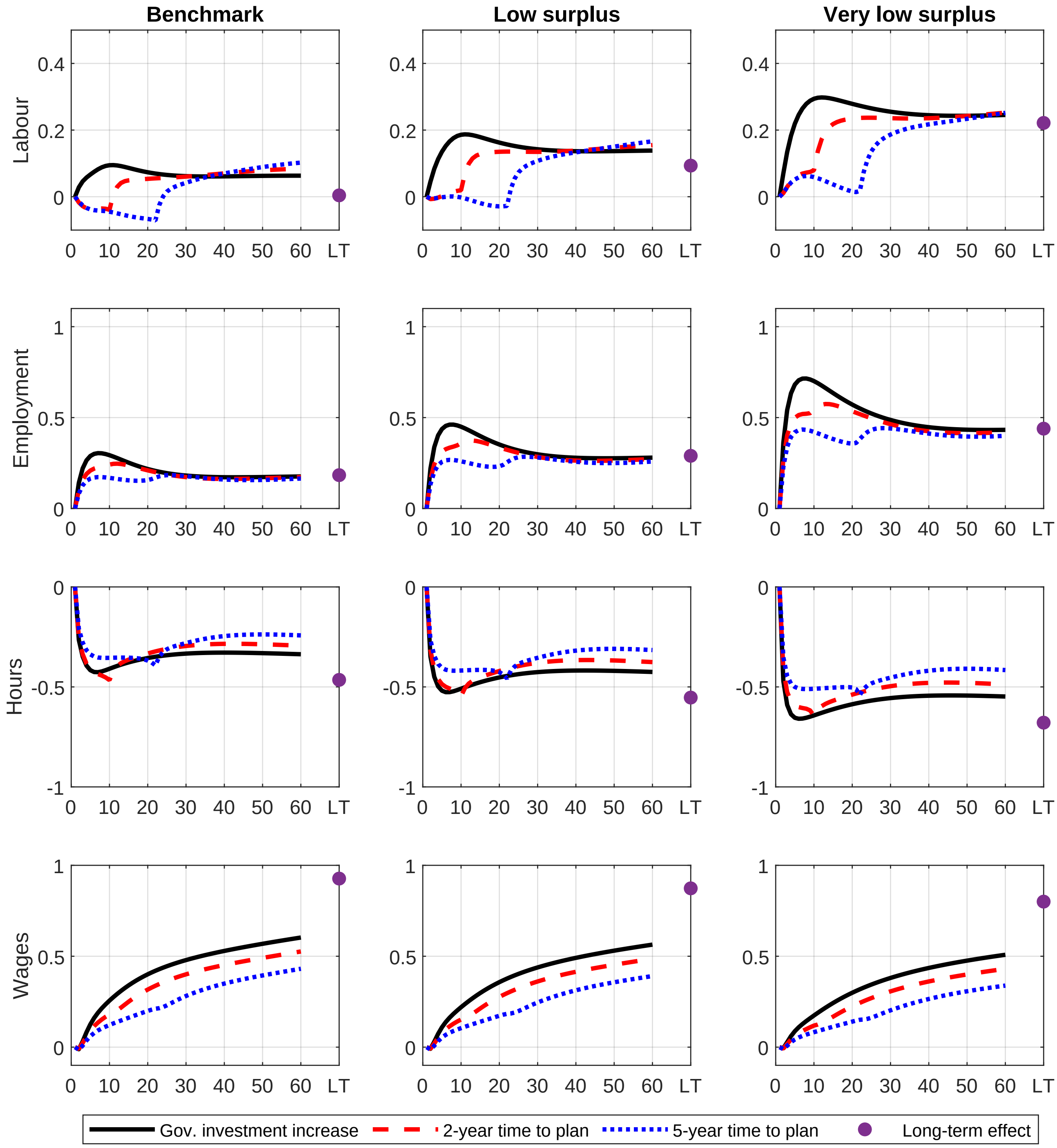
[22]In the long run, the increase in output, labour, consumption and investment is higher when the labour firm surplus is lower. This happens because lower surplus of labour firms implies that hours per capita are closer to 1, which implies that the nonlinearity in the production of hours worked by labour firms is in the less concave region.

FIGURE 5. Varying degree of search frictions: macroeconomic variables



Horizontal axes: quarters; vertical axes: percent deviations from the steady state, except inflation, which is in annualised p.p. deviations from the steady state. All variables are in real terms.

FIGURE 6. Varying degree of search frictions: labour market



Horizontal axes: quarters; vertical axes: percent deviations from the steady state. All variables are in real terms.

4.4 Welfare

In the model with the standard labour market and in the model with search (and in each case for both time-to-build and time-to-plan), most of the output increase occurs later in time if there are delays. However, in some cases, in particular in the case of planning delays with the standard labour market, labour falls during the planning phase. This could, in principle, be to some extent beneficial in terms of welfare, as households prefer leisure to work, despite the fact that consumption falls. Similarly, in the model with search, an early increase in labour that is disliked by the households could reduce the utility of households even though consumption increases. To assess these issues, we compute welfare of households, which is computed as the present value of household's utility, which is in turn defined by the utility of consumption and disutility of labour, as follows:

$$U_{s,t} = \left(\frac{1}{1-\sigma} \left(\frac{c_{s,t+k} - \kappa c_{s,t+k-1}}{1-\kappa} \right)^{1-\sigma} - \frac{1}{1+\zeta} h_{s,t+k}^{1+\zeta} \right) \tag{7}$$

where $s \in [i, \ j]$ stands for Ricardian (i) and hand-to-mouth (j) households, $c_{s,t}$ is consumption, β is the discount rate, σ is the inverse of the intertemporal elasticity of substitution and ζ is the (inverse of) the Frisch labour supply elasticity. κ is the degree of habit formation in consumption.[23] We include the fact that wage dispersion creates inefficiencies in allocation of labour and drives a wedge between labour demand from firms and labour supply by households, following Sims and Wolff (2018). Therefore, our measure of hours worked for welfare computation, $h_{s,t}$, includes the additional hours that occurs because of wage dispersion. Welfare is just the discounted present value of future utilities,

$$\mathcal{W}_{s,t} = \sum_{k=0}^{\infty} \beta^k U_{s,t+k}. \tag{8}$$

The aggregate welfare measure is just the present value of all future utilities, which we aggregate over the Ricardian and hand-to-mouth households using their respective shares, ω:

$$\mathcal{W}_t = \omega \mathcal{W}_{j,t} + (1-\omega)\mathcal{W}_{i,t} \tag{9}$$

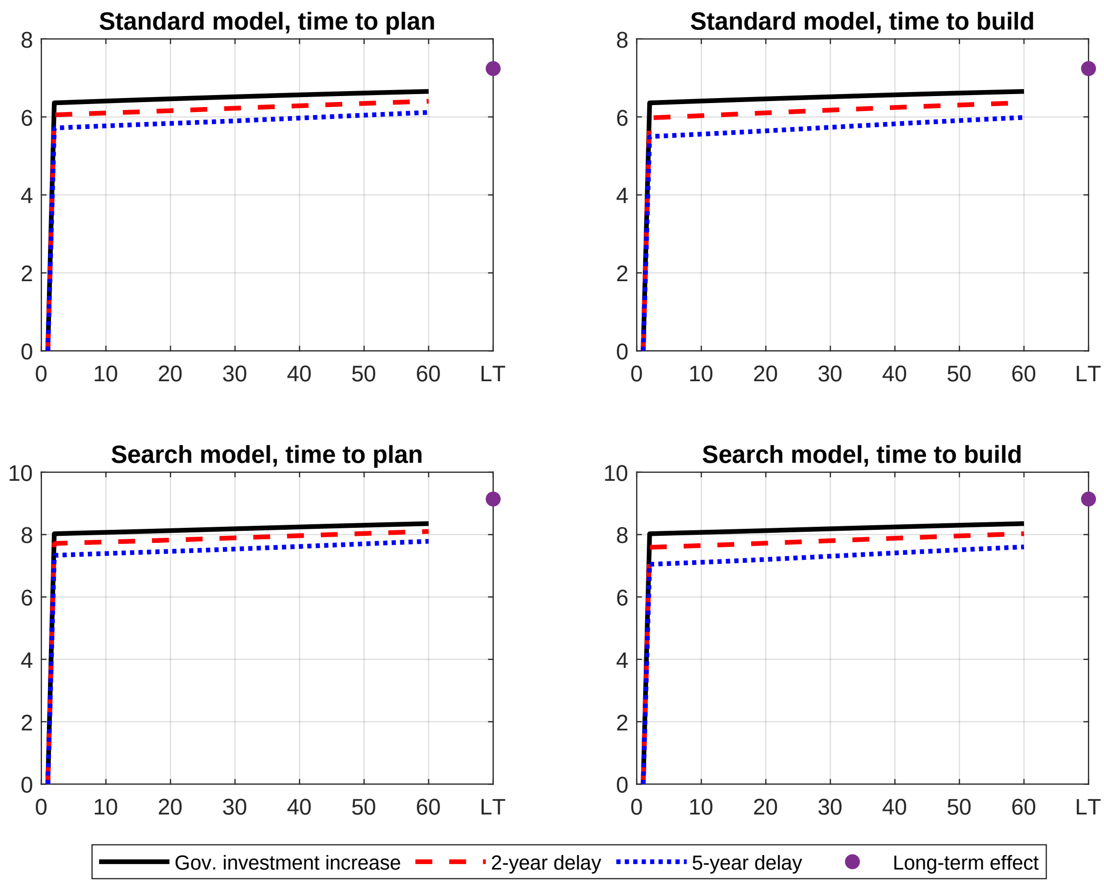
The results for welfare are shown in Figure 7, where the first row shows the results from the standard model and the second row shows the results from the search model. In both cases, welfare increases instantaneously upon announcement of the increase in public investment. This is because welfare is the present value of all future utilities, and the increase is mostly driven by the long-term effects (see equation 8). The long-run effects in turn are driven by productive public capital, and the stock of this capital increases when public investment goes up.

Delays of either type make relatively little difference in the short run (and no difference in the long run, as the final steady state is identical regardless of the length or the type of the delay). However, construction delays (time to build) generate somewhat larger differences between the lines showing welfare for different length of the delay, and this is the case in both models. The main reason is that in the case of time to build, construction commences immediately, and this implies an immediate increase in labour. Hours worked generate disutility, and this disutility is larger, the longer the time that is needed to build an investment project. In addition, the increase in labour occurs early

[23] To prevent that the value of κ affects the steady state, we divide the first term in the utility function with $1-\kappa$. This does not affect model dynamics.

and the disutility of working more is therefore not discounted as much as the future benefits.

FIGURE 7. Welfare



Horizontal axes: quarters; vertical axes: level deviations from the steady state.

5 Conclusion

We analyse planning and construction delays in a small open economy in a monetary union. We do so in two models, one that features a standard labour market with sticky wages, and one with the addition of search frictions on the labour market (with sticky nominal wages), but is otherwise identical. The comparison is related to the literature on news shocks about the future productivity, where it has been shown that the modelling choice can have different outcomes during the period of anticipation of the future productivity increase. That literature focused on productivity, but when public capital is productive, a delay related to public investment is akin to a news shock about future productivity. The novelty of our paper is that we focus on a small open economy in a monetary union, whereas the literature has mostly looked at real models of closed economies.

We find that delays in public investment, either due to planning or due to time needed for construction, result in the benefits from higher public capital occurring later in the future. From the business cycles perspective, planning and construction delays cause fluctuations not only immediately upon announcement, but also in the future, which may complicate the management of business cycles. This is particularly the case for planning delays, where future fluctuations tend to be stronger.

A standard model does not generate a Pigou cycle (a simultaneous increase in output, consumption, investment and labour) during the planning delay, but a search model does so, especially if the labour market is sufficiently reactive to news about the future. From a policy perspective, the presence of a Pigou cycle is helpful, because macroeconomic variables move in the same direction before and after the higher productivity of more public capital in the future materialises.

Delays in construction (time-to-build) produce similar results qualitatively (but not quantitatively) across both classes of models. From the perspective of business cycle management, construction delays are less problematic in the sense that they lead to a predictable immediate stimulus of the economy.

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A Outline of the standard model (without search frictions)

This section reports the equations of the core model. It closely follows the description fo the EAGLE model Gomes et al. (2012), and the reader should refer for all the details to that paper.

A.1 Households

There are two types of households in the model, Ricardian (unconstrained) and non-Ricardian (hand-to-mouth, HtM, or unconstrained). Their utilities are shown in equation 10:

$$U_{s,t} = \left(\frac{1}{1-\sigma} \left(\frac{c_{s,t+k} - \kappa c_{s,t+k-1}}{1-\kappa} \right)^{1-\sigma} - \frac{1}{1+\zeta} h_{s,t+k}^{1+\zeta,} \right) \tag{10}$$

where $c_{s,t}$ is consumption of type s households, $h_{s,t}$ is their hours worked, σ is the (inverse of) intertemporal elasticity of substitution, κ is the degree of habit formation and ζ is the (inverse of) the Frisch labour supply elasticity.

Ricardian households hold capital, invest in internationally traded bonds denominated in US dollars B_t^*, that pay the interest rate R_t^* set by the Federal reserve. They also hold domestic government bonds B_t that pay the rate R_t, which is determined by the European Central Bank. Investment in capital is subject to investment-adjustment costs that give rise to the standard Tobin's marginal q. The Euler equation with respect to domestic government bonds is

$$u'(c_{s,t}) = \beta \left(u'(c_{s,t+1}) \frac{R_t(1-\Gamma_{B,t+1})}{\pi_{t+1}} \right), \tag{11}$$

where $\Gamma_{B,t+1}$ is the transaction cost for the euro area traded bonds, which depends on the intra-EA bond holdings.[24] There is an analogous Euler equation for internationally traded bonds:

$$u'(c_{s,t}) = \beta \left(u'(c_{s,t+1}) \frac{R_t^*(1-\Gamma_{B^*,t+1})}{\pi_{t+1}^*} \frac{rer_{t+1}}{rer_t} \right), \tag{12}$$

where rer_t is the real exchange rate and Γ_{B^*} is the international transaction premium for US-denominated bonds, where $S_t^{H,US}$ is the nominal exchange rate, expressed in terms of units of Home currency per unit of US dollars:

$$\Gamma_{B^*} \left(\frac{S_t^{H,US} B_{t+1}^*}{P_{Y,t} Y_t}; rp_t \right) \equiv \gamma_{B^*} \left(\exp \left(\frac{S_t^{H,US} B_{t+1}^*}{P_{Y,t} Y_t} - \overline{B_Y^*} \right) - 1 \right) - rp_t \tag{13}$$

where γ_{B^*} is a parameter, $\overline{B_Y^*}$ is the steady-state net foreign asset position, rp_t is a risk premium shock, $P_{Y,t}$ is the GDP deflator, Y_t is the GDP in real terms. The term $\Gamma_{B,t+1}$ in the Euler equation for euro area bonds is analogous and depends on the target for intra-EA bond holdings. For further details see the Appendix in Gomes et al. (2010).

Ricardian households also invest I_t in physical capital K_t, which involves as:

[24] The bond traded in the union is in euros and the transaction cost is needed to stabilise the model.

$$K_{t+1} = (1-\delta)K_t + \left(1 - \Gamma_{I,t}\left(\frac{I_t}{I_{t-1}}\right)\right), \tag{14}$$

where δ is the depreciation rate and investment-adjustment cost is

$$\Gamma_{I,t}\left(\frac{I_t}{I_{t-1}}\right) \equiv \frac{\gamma}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2. \tag{15}$$

The first-order condition for investment in capital is:

$$p_{I,t} = q_{i,t}\left(1 - \Gamma_{I,t}\left(\frac{I_t}{I_{t-1}}\right) - \Gamma'_{I,t}\left(\frac{I_t}{I_{t-1}}\right)I_t\right) + \beta\frac{u'(c_{I,t+1})}{u'(c_{I,t})}q_{I,t+1}\Gamma'_{I,t}\left(\frac{I_t}{I_{t-1}}\right)\frac{I_{t+1}^2}{I_t}, \tag{16}$$

where primes indicate derivatives, $q_{I,t}$ is Tobin's q, and $p_{I,t} \equiv \frac{P_{I,t}}{P_{C,t}}$ is the relative price of investment goods.

$$q_{I,t} = \beta\frac{u'(c_{I,t+1})}{u'(c_{I,t})}\left[(1-\delta)q_{I,t+1} + (1-\tau_{t+1}^k)r_{K,t+1}u_{t+1} + \left(\tau_{t+1}^k\delta - (1-\tau_{t+1}^k)\Gamma(u_{t+1})\right)p_{I,t+1}\right], \tag{17}$$

where $r_{K,t}$ is the return on physical capital, u_t is capital utilisation, and $\Gamma(u_t)$ is capital utilisation adjustment cost.

Total capital services in the economy are the product of the capital stock and its utilisation, and are used by tradable $K_{T,t}$ and non-tradable $K_{N,t}$ sectors of intermediate goods firms:

$$u_t K_t = K_{N,t} + K_{T,t}. \tag{18}$$

A.2 Labour market

The labour market in the standard model is identical to what is typical in the literature - a standard staggered wage setting. This is the part where the main difference between the model with and without search frictions lies, namely, the standard part described briefly below is replaced by the fully-fledged search frictions, described in detail in Appendix B.

Households supply differentiated labour services in monopolistically competitive market for each type of labour service. Wages are determined by staggered wage setting in terms of nominal wages, where the probability that a wage contract is reset in a given period is $1-\xi_s$, where s stands for Ricardian or hand-to-mouth households. Households that can reset wage choose the same wage $\tilde{W}_{s,t}$, while wages that are not reset are indexed to past wages by a combination of the past CPI inflation, $\Pi_{C,t-1} = P_{C,t-1}/P_{C,t-2}$, where $P_{C,t}$ is the consumer price index, and inflation target, $\overline{\Pi}$, where the indexation weight is χ_s: $W_{t,i} = \Pi_{C,t-1}^{\chi_s}\overline{\Pi}^{1-\chi_s}W_{t-1,i}$. The first order condition for the optimal reset wage is

$$E_t\left[\sum_{k=0}^{\infty}(\beta\xi_s)^k\left(u'(c)_{s,t+k}(1-\tau_{t+k}^N - \tau_{t+k}^{W_h})\frac{\tilde{W}_{s,t}}{P_{C,t+k}}\left(\frac{P_{C,t+k-1}}{P_{C,t-1}}\right)^{\chi_s}\overline{\Pi}^{(1-\chi_s)k} - \frac{\eta_s}{\eta_s - 1}N_{t+k}^{\zeta}\right)N_{t+k}\right] = 0 \tag{19}$$

For details see the Appendix in Gomes et al. (2010).

A.3 Final goods

Final goods are consumption goods $Q_{C,t}$ and investment goods $Q_{I,t}$ (to save space, we list equations only for consumption goods, as the equations for investment goods are analogous). They are assembled from tradable goods, $TT_{C,t}$ and non-tradable goods, $NT_{C,t}$ using the constant elasticity of substitution technology:

$$Q_{C,t} = \left[\nu_C^{\frac{1}{\mu_C}} TT_{C,t}^{\frac{\mu_C - 1}{\mu_C}} + (1-\nu_C)^{\frac{1}{\mu_C}} NT_{C,t}^{\frac{\mu_C - 1}{\mu_C}} \right]^{\frac{\mu_C}{\mu_C - 1}}, \tag{20}$$

where:

$$TT_{C,t} = \left[\nu_{TC}^{\frac{1}{\mu_{TC}}} HT_{C,t}^{\frac{\mu_{TC} - 1}{\mu_{TC}}} + (1-\nu_{TC})^{\frac{1}{\mu_{TC}}} IM_{C,t}^{\frac{\mu_{TC} - 1}{\mu_{TC}}} \right]^{\frac{\mu_{TC}}{\mu_{TC} - 1}}. \tag{21}$$

Tradable goods are a composite bundle of of domestic tradable goods, $HT_{C,t}$, and imports, $IM_{C,t}$. Imports, in turn, are also a composite of imports from other regions CO, denoted by $IM_{C,CO,t}$, and H stands for the home country:

$$IM_{C,t} = \left[\sum_{CO \neq H} \left(\nu_{IM_C}^{H,CO} \right)^{\frac{1}{\mu_{IMC}}} \left(IM_{C,CO,t} \left(1 - \Gamma_{IM^C}^{H,CO} \left(\frac{IM_{C,CO,t}}{Q_{C,t}} \right) \right) \right)^{\frac{\mu_{IMC} - 1}{\mu_{IMC}}} \right]^{\frac{\mu_{IMC}}{\mu_{IMC} - 1}} \tag{22}$$

Parameters μ_C, μ_{TC}, and μ_{IMC} are intratemporal elasticities of substitution between the inputs in the production functions, while ν_C, ν_{TC}, and ν_{IM_C} are weights (quasi-shares) of the inputs into the production functions, with $\sum_{CO \neq H} v_{IM^C}^{H,CO} = 1$. The function $\Gamma_{IM^C}^{H,CO} \left(\frac{IM_{C,CO,t}}{Q_{C,t}^C} \right)$ is the adjustment cost for bilateral consumption imports of country H from country CO, where γ_{IM^C} determines the magnitude of the cost:

$$\Gamma_{IM^C}^{H,CO} \left(\frac{IM_{C,CO,t}}{Q_{C,t}} \right) \equiv \frac{\gamma_{IM^C}}{2} \left(\frac{IM_{C,CO,t}/Q_{C,t}}{IM_{C,CO,t-1}/Q_{C,t-1}} - 1 \right)^2. \tag{23}$$

A final goods firm chooses the combination of the tradable and nontradable bundles that minimizes the expenditure $P_{HT,t}HT_{C,t} + P_{IM^C,t}IM_{C,t} + P_{NT,t}NT_{C,t}$ subject to technology constraints (20) and (21), taking the input prices as given, which yields the following demand functions:

$$HT_{C,t} = \nu_{TC}\nu_C \left(\frac{P_{HT,t}}{P_{TT^C,t}} \right)^{-\mu_{TC}} \left(\frac{P_{TT^C,t}}{P_{C,t}} \right)^{-\mu_C} Q_{C,t} \tag{24}$$

$$IM_{C,t} = (1-\nu_{TC})\,\nu_C \left(\frac{P_{IM^C,t}}{P_{TT^C,t}} \right)^{-\mu_{TC}} \left(\frac{P_{TT^C,t}}{P_{C,t}} \right)^{-\mu_C} Q_{C,t} \tag{25}$$

$$NT_{C,t} = (1-\nu_C) \left(\frac{P_{NT,t}}{P_{C,t}} \right)^{-\mu_C} Q_{C,t} \tag{26}$$

$$IM_{C,CO,t} = \nu_{IM^C}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{P_{IM^C,t}\Gamma_{IM^C}^{H,CO\dagger}\left(IM_{C,CO,t}/Q_{C,t}\right)} \right)^{-\mu_{IMC}} \frac{IM_{C,t}}{1 - \Gamma_{IM^C}^{H,CO}\left(IM_{C,CO,t}/Q_{C,t}\right)} \tag{27}$$

The term $\Gamma_{IM^C}^{H,CO\dagger} \left(\frac{IM_{C,CO,t}}{Q_{C,t}} \right)$ in the bilateral import bundle is the derivative of the adjustment cost.

The corresponding cost-minimizing prices are:

$$P_{C,t} = \left[\nu_C P_{TT^C,t}^{1-\mu_C} + (1-\nu_C)\, P_{NT,t}^{1-\mu_C}\right]^{\frac{1}{1-\mu_C}} \tag{28}$$

$$P_{TT^C,t} = \left[\nu_{TC} P_{HT,t}^{1-\mu_{TC}} + (1-\nu_{TC})\, P_{IM^C,t}^{1-\mu_{TC}}\right]^{\frac{1}{1-\mu_{TC}}} \tag{29}$$

$$P_{IM^C,t} = \left(\sum_{CO\neq H} \nu_{IM^C}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{\Gamma_{IM^C}^{H,CO\dagger}\left(IM_t^{C,CO}/Q_{C,t}\right)}\right)^{1-\mu_{IMC}}\right)^{\frac{1}{1-\mu_{IMC}}}. \tag{30}$$

A.4 Export goods

The model features import-content of exports, which is modelled as in Brzoza-Brzezina et al. (2014), where export firms create a bundle of home-produced tradable goods for export, $HT_{X,t}$ and goods imported for the purpose of reexporting, $IM_{X,t}$, and then export the bundle of both goods. The export bundle is:

$$EX_t = \left[\nu_X^{\frac{1}{\mu_X}} HT_{X,t}^{\frac{\mu_X-1}{\mu_X}} + (1-\nu_X)^{\frac{1}{\mu_X}} IM_{X,t}^{\frac{\mu_x-1}{\mu_X}}\right]^{\frac{\mu_X}{\mu_X-1}}. \tag{31}$$

Analogously to demands for goods in the consumption bundle, we have the demands for home tradable goods for exports and imported goods for reexports:

$$HT_{X,t} = \nu_X \left(\frac{MC_{T,t}}{MC_{X,t}}\right)^{-\mu_X} EX_t \tag{32}$$

$$IM_{X,t} = (1-\nu_X)\left(\frac{P_{IM^X,t}}{MC_{X,t}}\right)^{-\mu_X} EX_t. \tag{33}$$

Imported goods for the purpose of reexports are a bundle of imported goods from all other regions, subject to adjustment costs:

$$IM_{X,t} = \left[\sum_{CO\neq H}\left(\nu_{IM_X}^{H,CO}\right)^{\frac{1}{\mu_{IMX}}}\left(IM_{X,CO,t}\left(1-\Gamma_{IM^X}^{H,CO}\left(\frac{IM_{X,CO,t}}{EX_t}\right)\right)\right)^{\frac{\mu_{IMX}-1}{\mu_{IMX}}}\right]^{\frac{\mu_{IMX}}{\mu_{IMX}-1}}. \tag{34}$$

These give rise to bilateral demands for reexport goods:

$$IM_{X,CO,t} = \nu_{IM^X}^{H,CO}\left(\frac{P_{IM,t}^{H,CO}}{P_{IM^X,t}\Gamma_{IM^X}^{H,CO\dagger}\left(IM_{X,CO,t}/EX_t\right)}\right)^{-\mu_{IMX}} \frac{IM_{X,t}}{1-\Gamma_{IM^X}^{H,CO}\left(IM_{X,CO,t}/EX_t\right)} \tag{35}$$

The real price (in terms of consumption goods) of the export good is just its marginal cost, $MC_{X,t}$, which is the weighted average of (real) marginal costs of home tradable goods, $MC_{T,t}$, and the relative price of imported goods for reexport, $P_{IM^X,t}$:

$$MC_{X,t} = \left[\nu_X MC_{T,t}^{1-\mu_X} + (1-\nu_X) P_{IM^X,t}^{1-\mu_X}\right]^{\frac{1}{1-\mu_X}}, \tag{36}$$

and the price of reexport good is the weighted average of the import prices from the regions where its components came from:

$$P_{IM^X,t} = \left(\sum_{CO \neq H} \nu_{IM^X}^{H,CO} \left(\frac{P_{IM,t}^{H,CO}}{\Gamma_{IM^X}^{H,CO\dagger} \left(IM_t^{X,CO} / EX_t \right)} \right)^{1-\mu_{IMX}} \right)^{\frac{1}{1-\mu_{IMX}}} . \tag{37}$$

A.5 Intermediate goods

Non-tradable ($Y_{N,t}$) and tradable ($Y_{T,t}$) intermediate goods are produced using a Cobb-Douglas technologies:

$$Y_{N,t} = z_{N,t} K_{G,t}^{\alpha_G} K_{N,t}^{\alpha_N} N_{N,t}^{1-\alpha_N} - \psi_N \tag{38}$$

$$Y_{T,t} = z_{T,t} K_{G,t}^{\alpha_G} K_{T,t}^{\alpha_T} N_{T,t}^{1-\alpha_T} - \psi_T \tag{39}$$

where ψ_N and ψ_T are fixed costs. The inputs are homogenous capital services, $K_{N,t}$ and K_{NTt}, and labour services, $N_{N,t}$ and $N_{N,t}$. Capital services are supplied by domestic households under perfect competition, yielding that demand for capital is determined by its marginal product being equal to the rental rate, while labour demand is determined by the marginal product of labour at intermediate goods firm being equal to the cost of labour determined by labour packers, as described in the main text. $z_{N,t}$ and $z_{T,t}$ are sector-specific productivity shocks.

Note that the labour market clearing implies that the total labour services provided must equal to the labour demanded by intermediate goods firms:

$$n_t = N_{N,t} + N_{T,t}. \tag{40}$$

Goods markets for non-tradable and tradable goods clear by equating supply and demand. Demand for non-tradable goods comes from demands for non-tradable consumption and investment goods, ($NT_{C,t}$ and $NT_{I,t}$), and from government (G_t), which is fully biased towards non-tradable goods. Demand for tradable goods comes from demands for tradable consumption and investment goods ($HT_{C,t}, HT_{I,t}$) and from trading partners' imports ($IM_{CO,H,t}$). $s_{N,t}$, $s_{HT,t}$, and $s_{X,t}^{H,CO}$ are price dispersions in non-tradable, tradable, and export sectors:

$$Y_{N,t} = s_{N,t} \left(NT_{C,t} + NT_{I,t} + G_t \right) \tag{41}$$

$$Y_{T,t} = s_{HT,t}(HT_{C,t} + HT_{I,t}) + \sum_{CO \neq H} s_{X,t}^{H,CO} IM_{CO,H,t} \tag{42}$$

A.6 Price setting

Price setting follows the standard Calvo (1983) framework. Intermediate goods firms, however, set prices differently, depending on the market to which they are pricing their goods. This applies to non-tradable, home tradable and to export goods, in the latter case also for each export market separately (the so-called local currency pricing framework). Prices that are not reset are indexed to a composite of past inflation and inflation target.

Price setting for non-tradable goods. All non-tradable goods firms that are able to reset their prices, which happens with the probability $1 - \xi_N$, choose the same price $\widetilde{P}_{NT,t}$. Firms that do not reset their prices index their prices according to $P_t = (\Pi_{NT,t-1})^{\chi_N} \overline{\Pi}^{1-\chi_N} P_{t-1}$, i.e., to a geometric average of past sector-specific inflation, $\Pi_{NT,t-1} \equiv P_{NT,t-1}/P_{NT,t-2}$ and the (constant) inflation target, $\overline{\Pi}$. The parameter χ_N measures the degree of indexation. Reoptimising firm maximizes the discounted sum of its expected nominal profits subject to the price-indexation scheme and taking as given the demand for its brand. The marginal costs $MC_{N,t}$ are symmetric across producers. $\Lambda_{i,t,t+k}$ is the stochastic discount factor of i-type households, who own firms.

The implied first-order condition is:

$$E_t \left[\sum_{k=0}^{\infty} (\xi_N)^k \Lambda_{i,t,t+k} \left(\prod_{s=1}^{k} \Pi_{NT,t+s-1}^{\chi_N} \overline{\Pi}^{1-\chi_N} \widetilde{P}_{NT,t} - \frac{\theta_N}{\theta_N - 1} MC_{N,t+k} \right) NT_{t+k} \right] = 0 \quad (43)$$

Firms whose price contracts are re-optimized set prices to equate the discounted sum of expected revenues to the discounted sum of expected marginal costs.

With price setting as described above, the sector-specific price index $P_{NT,t}$ is:

$$P_{NT,t} = \left[\xi_N \left(\Pi_{NT,t-1}^{\chi_N} \overline{\Pi}^{1-\chi_N} P_{NT,t-1} \right)^{1-\theta_N} + (1 - \xi_N) \left(\widetilde{P}_{NT,t} \right)^{1-\theta_N} \right]^{\frac{1}{1-\theta_N}} \quad (44)$$

Price setting for home tradable goods. Price setting for home tradable goods is analogous to that of non-tradable goods. The probability of resetting the price is $(1-\xi_H)$. The sector-specific price index $P_{HT,t}$ evolves according to:

$$P_{HT,t} = \left[\xi_H \left(\Pi_{HT,t-1}^{\chi_H} \overline{\Pi}^{1-\chi_H} P_{HT,t-1} \right)^{1-\theta_T} + (1 - \xi_H) \left(\widetilde{P}_{HT,t} \right)^{1-\theta_T} \right]^{\frac{1}{1-\theta_T}} \quad (45)$$

Price setting for export goods. Firms discriminates across countries, by invoicing and setting the price in the currency of the generic destination market CO (local currency pricing assumption). The probability of optimally resetting prices $(1 - \xi_X)$, and all firms that reset their prices choose the same price, $\widetilde{P}_{X,t}^{H,CO}$, while the others index their prices to $P_{X,t}^{CO} = \left(\Pi_{X,t-1}^{H,CO}\right)^{\chi_X} \overline{\Pi}^{1-\chi_X} P_{X,t-1}^{CO}$, where $\Pi_{X,t-1}^{H,CO} \equiv P_{X,t-1}^{H,CO}/P_{X,t-2}^{H,CO}$ is the sector-specific inflation. Foreign inflation target is time invariant and equal to the Home inflation target, $\overline{\Pi}^{CO} = \overline{\Pi}$.

The bilateral exports price index (of country H to the generic country CO) is:

$$P_{X,t}^{H,CO} = \left[\xi_X \left(\left(\Pi_{X,t-1}^{H,CO}\right)^{\chi_X} \overline{\Pi}^{1-\chi_X} P_{X,t-1}^{H,CO} \right)^{1-\theta_T} + (1 - \xi_X) \left(\widetilde{P}_{X,t}^{H,CO} \right)^{1-\theta_T} \right]^{\frac{1}{1-\theta_T}} \quad (46)$$

B Outline of the model with search frictions

This appendix if based on, and follows closely the model description in Gomes et al. (2023), and the reader should refer to this paper for all the details. The labour market structure with search frictions follows the standard search model of Mortensen and Pissarides (1999), but adds sticky wages by means of staggered wage setting, and a potential to distinguish wage stickiness of new hires and existing workers, as in Bodart et al. (2006) and De Walque et al. (2009). In addition, it distinguishes between labour market segments for Ricardian and non-Ricardian households.

The number of workers in segment s ($s = i$ for Ricardian and $s = j$ for non-Ricardian households) that are employed after the matching process has been completed, $nde_{s,t}$, is:

$$nde_{s,t} = (1 - \delta_{x,s})\, nde_{s,t-1} + M_{s,t}, \tag{47}$$

where $M_{s,t}$ is the number of new matches formed in a period, and $\delta_{x,s}$ is the fraction of existing employment relationships that have (exogenously) separated. The number of matches $M_{s,t}$ is:

$$M_{s,t} = \phi_{s,M}(un_{s,t})^{\mu_s}(vac_{s,t})^{1-\mu_s} = p^W_{s,t} un_{s,t} = p^F_{s,t} vac_{s,t}, \tag{48}$$

where $\phi_{s,M}$ is matching efficiency, $un_{s,t}$ is the number of searching workers in each segment, $vac_{s,t}$ is the number of vacancies, $p^W_{s,t}$ is the matching probability for workers of each type, $p^F_{s,t}$ is the matching probability for firms, and μ_s is the elasticity of the matching function with respect to unemployment.

The probability for a searching worker to find a job is

$$p^W_{s,t} = \frac{M_t}{un_{s,t}} = \phi_{s,M}(\frac{vac_{s,t}}{un_{s,t}})^{1-\mu_s} \tag{49}$$

and the probability of a firm finding a worker is

$$p^F_{s,t} = \frac{M_{s,t}}{vac_{s,t}} = \phi_{s,M}(\frac{vac_{s,t}}{un_{s,t}})^{-\mu_s} \tag{50}$$

The number of unemployed workers who search for work at the beginning of period t is equal to those who were unemployed at the end of period $t-1$ after the $t-1$ matching has been completed plus the newly separated workers:

$$un_{s,t} = une_{s,t-1} + \delta_{x,s} nde_{s,t-1}, \tag{51}$$

Total unemployment in a bloc is a weighted unemployment across labour market segments, where ω is the share of non-Ricardian households: $une_t = \omega\, une_{j,t} + (1 - \omega) une_{i,t}$.

B.1 Value functions

Value functions for a labour firm Let $A^F(w^*_{s,t})$ denote the value of a job for a firm employing a worker from household type $s \in [i,\ j]$, where $w^*_{s,j}$ is the renegotiated wage, and i stands for a Ricardian and j for a non-Ricardian household. Following Bodart et al. (2006), it will be convenient to use this value in marginal utility terms, so we define $\mathcal{A}^F(w^*_{s,t}) \equiv u'(c_{s,t}) A^F(w^*_{s,t})$, where $u'(c_{s,t})$ is the marginal utility of consumption of household s. The value of a job with a renegotiated wage for a labour firm can then be written as

$$\begin{aligned} \mathcal{A}^F_t(w^*_{s,t}) = u'(c_{s,t}) \left(h^{\alpha_H}_{s,t} x_{s,t} - h_{s,t} w^*_{s,t}(1 + \tau^{wf}_t) \right) \\ + \beta(1 - \delta_{x,s}) \left[(1 - \xi_{w,s}) \mathcal{A}^F_{t+1}(w^*_{s,t+1}) + \xi_{w,s} \mathcal{A}^F_{t+1}(w^*_{s,t}) \right] \end{aligned} \tag{52}$$

The term $h_{s,t}^{\alpha_H}$ denotes the effective hours that a labour firm produces from hours $h_{s,t}$ supplied by the worker from household s. $x_{s,t}$ is what the labour packer pays for such unit of labour. The first term in equation 52 therefore measures earnings of the labour firm from selling hours worked. But for these hours it has to pay to the household hourly wage, which is in this case newly renegotiated, $w_{s,t}^*$. Because we assume that labour firms pay some labour taxes (social security contributions), the cost for the labour firm is increased by taxes paid, at the rate τ_t^{wf}. In the next period, if the firm and the worker do not separate, which occurs with probability $(1-\delta_{x,s})$, two cases can arise. In the first case, which occurs with the probability $(1-\xi_{w,s})$, wages are renegotiated and the value of the worker for the labour firm is again the value of a worker with a renegotiated wage, just in the next period, $\mathcal{A}_{t+1}^F(w_{s,t+1}^*)$. With probability $\xi_{w,s}$ wages are not renegotiated and the firm is in next period stuck with the worker value at the current wage, $\mathcal{A}_{t+1}^F(w_{s,t}^*)$.

The value at $t+1$ of the worker with renegotiated wage from time t is

$$\begin{aligned}\mathcal{A}_{t+1}^F(w_{s,t}^*) = u'(c_{s,t+1})\left(h_{s,t+1}^{\alpha_H}x_{s,t+1} - h_{s,t+1}w_{s,t}^*\frac{(1+\overline{\pi})P_t}{P_{t+1}}(1+\tau_{t+1}^{wf})\right) \\ + \beta(1-\delta_{x,s})\left[(1-\xi_{w,s})\mathcal{A}_{t+2}^F(w_{s,t+2}^*) + \xi_{w,s}\mathcal{A}_{t+2}^F(w_{s,t}^*)\right]\end{aligned} \tag{53}$$

The wage from the previous period has been indexed by the ratio of trend inflation $\overline{\pi}$ and the price level growth, $P_t/P_{t+1} = (1+\pi_{t+1})$.

If we substitute equation 53 into equation 52, and do this for every future period, we arrive at the following expression:

$$\begin{aligned}\mathcal{A}_t^F(w_{s,t}^*) = &\sum_{k=0}^{\infty}\left[\beta(1-\delta_{x,s})\xi_{w,s}\right]^k u'(c_{s,t+k})h_{s,t+k}^{\alpha_H}x_{s,t+k} \\ &- w_{s,t}^*\sum_{k=0}^{\infty}\left[\beta(1-\delta_{x,s})\xi_{w,s}\right]^k u'(c_{s,t+k})\frac{(1+\overline{\pi})^k P_t}{P_{t+k}}h_{s,t+k}(1+\tau_{t+k}^{wf}) \\ &+ \sum_{k=0}^{\infty}\beta(1-\delta_{x,s})(1-\xi_{w,s})\left[\beta(1-\delta_{x,s})\xi_{w,s}\right]^k \mathcal{A}_{t+k+1}^F(w_{s,t+k+1}^*)\end{aligned} \tag{54}$$

One can define auxiliary variables and write the infinite sums in recursive form. For the first line in equation 54, define

$$S_{s,t}^x \equiv \sum_{k=0}^{\infty}\left[\beta(1-\delta_{x,s})\xi_{w,s}\right]^k u'(c_{s,t+k})h_{s,t+k}^{\alpha_H}x_{s,t+k} = u'(c_{s,t})h_{s,t}^{\alpha_H}x_{s,t} + \beta(1-\delta_{x,s})\xi_{w,s}S_{s,t+1}^x \tag{55}$$

For the second line, define

$$\begin{aligned}S_{s,t}^{wf} &\equiv \sum_{k=0}^{\infty}\left[\beta(1-\delta_{x,s})\xi_{w,s}\right]^k u'(c_{s,t+k})h_{s,t}\frac{(1+\overline{\pi})^k P_t}{P_{t+k}}(1+\tau_t^{wf}) \\ &= u'(c_{s,t})h_{s,t}(1+\tau_t^{wf}) + \beta(1-\delta_{x,s})\frac{(1+\overline{\pi})}{(1+\pi_{t+1})}\xi_{w,s}S_{s,t+1}^{wf}\end{aligned} \tag{56}$$

Using these definitions, we can simplify equation 54 to

$$\mathcal{A}_t^F(w_{s,t}^*) = \left(S_{s,t}^x - S_{s,t}^{wf} w_{s,t}^*\right) + \sum_{k=0}^{\infty} \beta(1-\delta_{x,s})(1-\xi_{w,s}) \left[\beta(1-\delta_{x,s})\xi_{w,s}\right]^k \mathcal{A}_{t+k+1}^F(w_{s,t+k+1}^*)$$
$$= \left(S_{s,t}^x - S_{s,t}^{wf} w_{s,t}^*\right) - \beta(1-\delta_{x,s})\xi_{w,s} \left(S_{s,t+1}^x - S_{s,t+1}^{wf} w_{s,t+1}^*\right) + \beta(1-\delta_{x,s})\mathcal{A}_{t+1}^F(w_{s,t+1}^*) \tag{57}$$

After rearranging, we obtain the second line.

We can then similarly define the value of a worker with an average wage for a labour firm:

$$\begin{aligned}\mathcal{A}_t^F(w_{s,t}) &= u'(c_{s,t}) \left(h_{s,t}^{\alpha_H} x_{s,t} - h_{s,t} w_{s,t}(1+\tau_t^{wf})\right) \\ &\quad + \beta(1-\delta_{x,s}) \left[(1-\xi_{w,s})\mathcal{A}_{t+1}^F(w_{s,t+1}^*) + \xi_{w,s}\mathcal{A}_{t+1}^F(w_{s,t})\right]\end{aligned} \tag{58}$$

Following the same steps as above, we obtain, after some algebra

$$\mathcal{A}_t^F(w_{s,t}) = \left(S_{s,t}^x - S_{s,t}^{wf} w_{s,t}\right) - \beta(1-\delta_{x,s})\xi_{w,s} \left(S_{s,t+1}^x - S_{s,t+1}^{wf} w_{s,t+1}\right) + \beta(1-\delta_{x,s})\mathcal{A}_{t+1}^F(w_{s,t+1}) \tag{59}$$

Free entry condition A firm posting a vacancy for household type s must pay a per-period constant cost ψ_s for having a vacancy open. If $\kappa_{w,s}$ denotes the probability that a firm cannot renegotiate the wage for a newly hired worker from household type s, then the value of employing a new worker is, in monetary terms (recall, $\mathcal{A}^F(w_{s,t}^*) \equiv u'(c_{s,t})A^F(w_{s,t}^*)$, and the same for the value at average wage), equal to the weighted average of the value of a worker at a newly-renegotiated job and the value of a worker hired at average wage. The free-entry condition is:

$$\psi_s = p_t^F \beta \frac{u'(c_{s,t+1})}{u'(c_{s,t})} \left[(1-\kappa_{w,s})\mathcal{A}_t^F(w_{s,t+1}^*) + \kappa_{w,s}\mathcal{A}_t^F(w_{s,t+1})\right]. \tag{60}$$

Value functions for a worker We have two types of value functions, one for a newly-renegotiated wage and one for the average wage, for each type of household. The value of a job, net of the value of unemployment, for a worker with newly-renegotiated wage is

$$\begin{aligned}\mathcal{A}_t^H(w_{s,t}^*) &= u'(c_{s,t}) \left(h_{s,t} w_{s,t}^*(1-\tau_t^{wh}) - b_{s,t}\right) - \chi \frac{h_{s,t}^{1+\varphi}}{1+\varphi} \\ &\quad + \beta(1-\delta_{x,s}) \left[(1-\xi_{w,s})\mathcal{A}_{t+1}^H(w_{s,t+1}^*) + \xi_{w,s}\mathcal{A}_{t+1}^H(w_{s,t}^*)\right] \\ &\quad - \beta p_{s,t}^W \left[(1-\kappa_{w,s})\mathcal{A}_{t+1}^H(w_{s,t+1}^*) + \kappa_{w,s}\mathcal{A}_{t+1}^H(w_{s,t+1})\right]\end{aligned} \tag{61}$$

We can define additional auxiliary variables to sum the utility obtained from wages, unemployment benefits, and the disutility of labour terms,

$$
\begin{aligned}
S^{wh}_{s,t} &\equiv \sum_{k=0}^{\infty} \left[\beta(1-\delta_{x,s})\xi_{w,s}\right]^k u'(c_{s,t+k}) h_{s,t} \frac{(1+\overline{\pi})^k P_t}{P_{t+k}} (1-\tau^{wh}_t) \\
&= u'(c_{s,t}) h_{s,t} (1-\tau^{wh}_t) + \beta(1-\delta_{x,s}) \frac{(1+\overline{\pi})}{(1+\pi_{t+1})} \xi_{w,s} S^{wh}_{s,t+1},
\end{aligned} \tag{62}
$$

$$
S^b_{s,t} = u'(c_{s,t+k}) b_{s,t} + \beta(1-\delta_{x,s})\xi_{w,s} \frac{(1+\overline{\pi})}{(1+\pi_{t+1})} S^b_{s,t+1}, \tag{63}
$$

$$
S^h_{s,t} = \chi \frac{h^{1+\varphi}_{s,t}}{1+\varphi} + \beta(1-\delta_{x,s})\xi_{w,s} S^h_{s,t+1}, \tag{64}
$$

then the net value of a job for a new wage for the household is:

$$
\begin{aligned}
\mathcal{A}^H_t(w^*_{s,t}) = {} & S^w_{s,t} w^*_{s,t} - S^b_{s,t} - \beta(1-\delta_{x,s})\xi_{w,s}\left(S^w_{t+1} w^*_{s,t+1} - S^b_{s,t+1}\right) \\
& - S^h_{s,t} + \beta(1-\delta_{x,s})\xi_{w,s} S^h_{s,t+1} \\
& + \beta\left[1-\delta_{x,s} - (1-\kappa_{w,s}) p^W_{s,t}\right] \mathcal{A}^H_{t+1}(w^*_{s,t+1}) - \beta\kappa_{w,s} p^W_{s,t} \mathcal{A}^H_{t+1}(w_{s,t+1})
\end{aligned} \tag{65}
$$

The value of a job for an average wage for the household is:

$$
\begin{aligned}
\mathcal{A}^H_t(w_{s,t}) = {} & S^w_{s,t} w_{s,t} - S^b_{s,t} - \beta(1-\delta_{x,s})\xi_{w,s}\left(S^w_{s,t+1} w_{s,t+1} - S^b_{s,t+1}\right) \\
& - S^h_{s,t} + \beta(1-\delta_{x,s})\xi_{w,s} S^h_{s,t+1} \\
& + \beta\left[(1-\delta_{x,s})(1-\xi_{w,s}) - (1-\kappa_{w,s}) p^W_{s,t}\right] \mathcal{A}^H_{t+1}(w^*_{s,t+1}) \\
& + \beta\left[(1-\delta_{x,s})\xi_{w,s} - \kappa_{w,s} p^W_{s,t}\right] \mathcal{A}^H_{t+1}(w_{s,t+1})
\end{aligned} \tag{66}
$$

B.2 Wages and hours

Wages and hours are determined using efficient Nash bargaining, so that every period, wages and hours worked are determined by maximising the following expression, where η_s is the bargaining power of workers of type s:

$$
\max_{w^*_{s,t}, h_{s,t}} \left(A^H_t(w^*_{s,t})\right)^{\eta_s} \left(A^F_t(w^*_{s,t})\right)^{1-\eta_s}. \tag{67}
$$

The Nash sharing rule is:

$$
\eta_s (1-\tau^{wh}_t) A^F_t(w^*_{s,t}) = (1-\eta_s)(1+\tau^{wf}_t) A^H_t(w^*_{s,t}). \tag{68}
$$

This equation thus determines $w^*_{t,s}$.

The average wage is determined by using the law of motion of labour as follows:

$$
\begin{aligned}
nde_{s,t} h_{s,t} w_{s,t} = {} & (1-\delta_{x,s}) nde_{s,t-1} \left[\xi_{w,s} \frac{1+\overline{\pi}}{1+\pi_{t-1}} w_{s,t-1} h_{s,t} + (1-\xi_{w,s}) w^*_{s,t} h_{s,t}\right] \\
& + M_{s,t}\left[\kappa_{w,s} w_{s,t} h_{s,t} + (1-\kappa_{w,s}) w^*_{s,t} h_{s,t}\right],
\end{aligned} \tag{69}
$$

where the first row is the average wage of existing workers and the second row is the average wage of new hires, with the number of new matches $M_{s,t}$ counting the number of new hires.

Hours worked are determined by per-period Nash bargaining, and after taking into account the wage decision (equation 68), hours worked expression is:

$$\alpha_H x_{s,t}(h_{s,t})^{\alpha_{H-1}} = \frac{\chi}{u'(c_{s,t})} \frac{(1+\tau_t^{wf})}{(1-\tau_t^{wh})}(h_{s,t})^{\varphi}. \tag{70}$$

B.3 Labour packer

Labour from Ricardian and non-Ricardian households is aggregated by a labour packer using a CES technology, as follows:

$$n_t^{1-\frac{1}{\eta}} = \left[(1-\omega)^{\frac{1}{\eta}} \left(nde_{i,t} h_{i,t}^{\alpha_H}\right)^{1-\frac{1}{\eta}} + \omega^{\frac{1}{\eta}} \left(nde_{j,t} h_{j,t}^{\alpha_H}\right)^{1-\frac{1}{\eta}}\right], \tag{71}$$

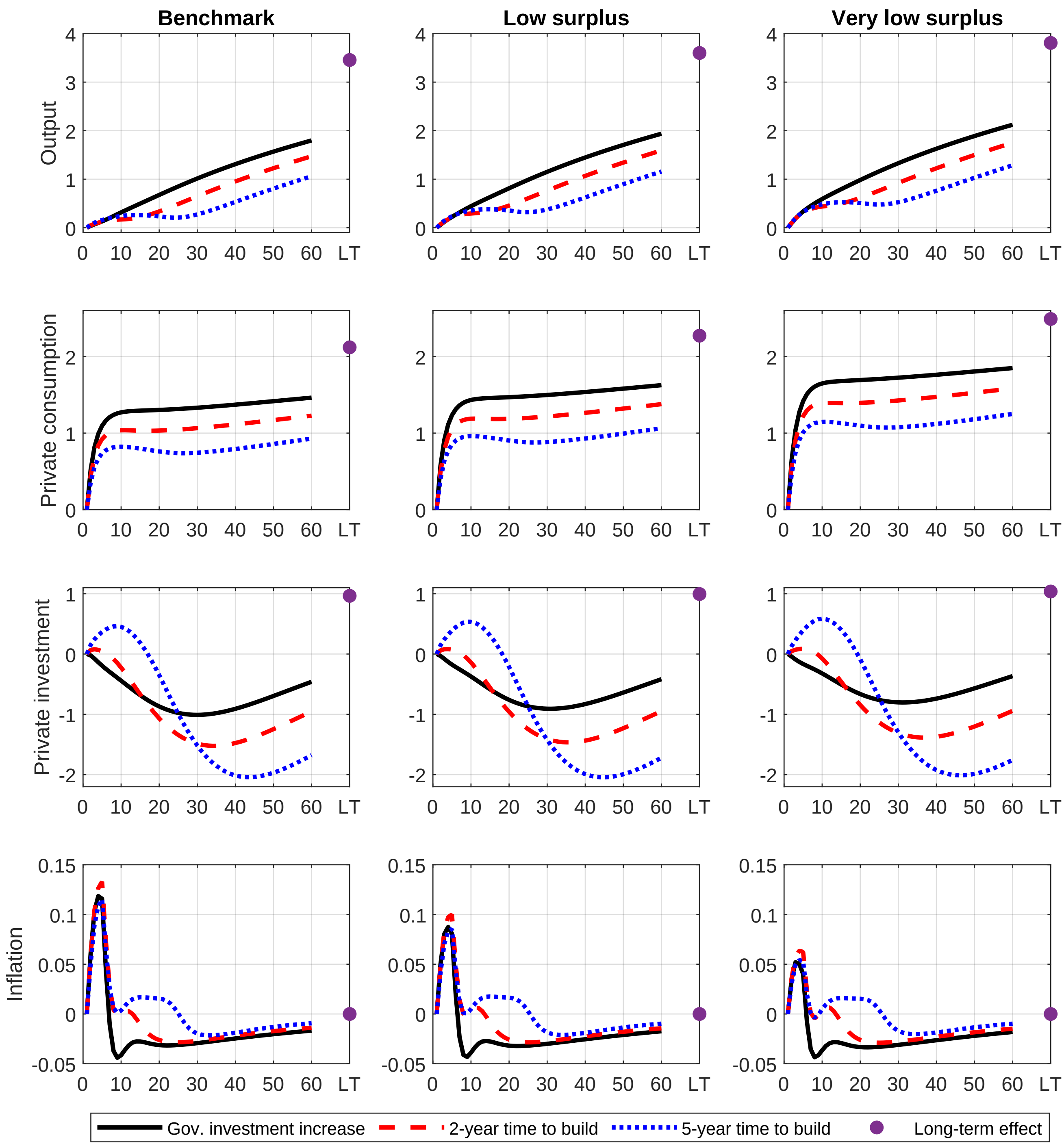
where n_t are aggregate labour services and $nde_{s,t} h_{s,t}^{\alpha_H}$ are total labour services provided by labour firms in household segment s. Parameter ω measures the share of non-Ricardian households in the economy.

C Search frictions and time to build

Here we briefly discuss the implications of more volatile labour market when the delays are related to construction rather than planning. As discussed in the main text, this case is less interesting from the perspective of the news shocks literature than a planning delay, because there is an immediate stimulus of the economy from government spending on public investment (rather than no immediate stimulus in the case of the planning delay). The news of the future productivity of higher level of public capital is, however, identical in the case of planning and construction delays.

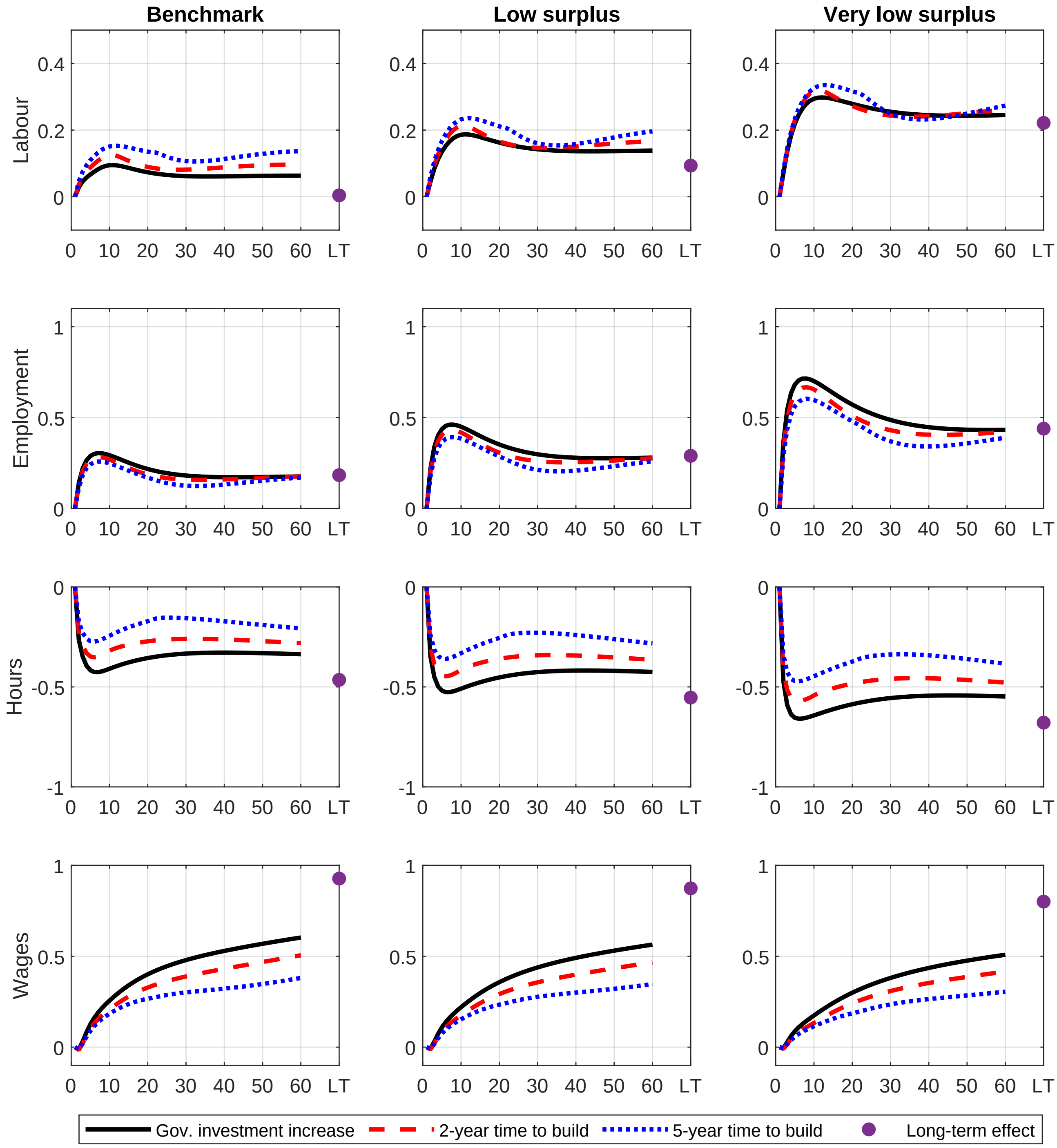
The results of the time to build delay are shown in Figure 8 for the main macroeconomic variables and in Figure 9 for the labour market variables. The main findings are similar than for planning delays: the increases in consumption, investment, and labour during the construction phase are somewhat larger if the labour market is more volatile. On the other hand, the increase in inflation is more dampened, which happens for the same reason as in the case of planning delays, i.e., an early increase in hiring causes and increase in labour, which dampens the increase in firms' marginal costs and therefore inflation. Long-run results are identical in the case of planning or construction delays, as the final steady state does not depend on the delay.

FIGURE 8. Varying degree of search frictions: macroeconomic variables



Horizontal axes: quarters; vertical axes: percent deviations from the steady state, except inflation, which is in annualised p.p. deviations from the steady state. All variables are in real terms.

FIGURE 9. Varying degree of search frictions: labour market



Horizontal axes: quarters; vertical axes: percent deviations from the steady state. All variables are in real terms.

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